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Control of Volatile Organic Emissions from Manufacture of Vegetable Oils

PEDCo-Environmental, Inc, Cincinnati, OH

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Environmental Protection Agency, Research Triangle Park, NC Office of Air Quality Planning and Standards

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This report provides the necessary guidance for development of regulations limiting emissions of volatile organic compounds (VOC) from the manufacture of vegetable oil. Only soybean, cottonseed, corn, and peanut oil manufacturing facilities are addressed in this document.

Reasonably available control technology (RACT) is defined in this document and cost analysis for RACT is included for evaluating the cost effectiveness of controlling vegetable oil plants.

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Emission Standards and Engineering Division
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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air, Noise, and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, North Carolina 27711

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ABBREVIATIONS AND CONVERSION FACTORS

EPA policy is to express all measurements in agency documents in metric units. Listed below are abbreviations and conversion factors for British equivalents of metric units.

Abbreviation	Conversion Factor
g - gram	1g = 0.0022 lbm
kg - kilogram	1kg = 2.2 lbm
Mg - megagram	1Mg = 10^6 = 2.2 x 10^3 lbm
Gg - gigagram	1Gg = 10^9g = 2.2 x 10^6 lbm
MFC - Mg of extractor feed cake	
TFC - Tons of extractor feed cake	1 TFC = 0.91 MFC
acf - actual cubic feet	acf = $\frac{Pscf(Tacf)}{Pacf(Tscf)}$ x scf
scf - standard cubic feet	where Pscf and Pacf are in like units, Tacf and Tscf are absolute
m^3 - cubic meter	1 m^3 = 35.314 ft^3 = 264 gal.
m, cm - meter, centimeter	1 m = 3.28 ft = 100 cm
^oC - degrees centigrade	$\frac{9}{5}$ (^oC) + 32 = ^oF
J - joule	1 joule = 9.5 x 10^{-4} BTU
kJ - kilojoule	1 kJ = 9.5 x 10^{-1} BTU
kJ/kw - kilojoule per kilowatt	10,550 kJ/kw = 10,000 BTU/kw
kJ/kg - kilojoule per kilogram	2300 kJ/kg = 1000 BTU/lb steam
GJ - gigajoule	1 GJ = 950 BTU
kw - kilowatt	1 kw = 1.34 x 10^{-3} hp
mmHg - millimeters of mercury	760 mmHg = 1 atm = 14.7 psi
ppm - parts per million	ppm x 10^{-4} = volume percent

GLOSSARY

- Crude oil is vegetable oil remaining after solvent/oil distillation.
- Desolventizer means a process unit in which steam is used to strip occluded solvent out of the extractor meal.
- Extraction means leaching of vegetable oil from the seed or bean typically using a hexane solvent in a countercurrent contact system. Extraction products are leached seed (meal) and miscella (oil-solvent mixture).
- Feed cake means extractor feed composed of clean, dehulled, conditioned and flaked beans (or seeds).
- Full solvent plant is a vegetable oil plant exclusively utilizing solvent extraction to produce vegetable oil.
- Meal means leached seed or bean flakes remaining after extraction.
- Mineral Oil Scrubber (MOS) is a packed tower using mineral oil as absorbent for solvent laden vapors.
- Miscella is the mixture of solvent and extracted oil.
- Prepress plant is a vegetable oil plant which mechanically removes a portion of the oil prior to solvent extraction. In most cases, continuous screw presses are used to "squeeze" the oil out.
- Vegetable oil plant is any facility engaged in the manufacture of vegetable oil from soybeans, corn, cottonseed, or peanuts.
- Volatile organic compounds (VOC) means organic compounds which under favorable conditions may participate in photochemical reactions to form oxidants.

1.0 INTRODUCTION

This document is related to the control of volatile organic compounds (VOC) from soybean, cottonseed, peanut, and corn oil manufacturing and refining facilities (hereafter "vegetable oil plants"). The specific sources discussed herein are the extractor, desolventizer-toaster, dryer, cooler, and pneumatic conveyor.

Methodology described in this document represents the presumptive norm or reasonably available control technology (RACT) that can be applied to existing vegetable oil plants. RACT is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical, source categories. It is not intended that extensive research and development be conducted before a given control technology can be applied to the source. This does not, however, preclude requiring a short-term evaluation program to permit the application of a given technology to a particular source. This latter effort is an appropriate technology-forcing aspect of RACT.

1.1 NEED TO REGULATE VEGETABLE OIL PLANTS

Control techniques guidelines concerning RACT are being prepared for those industries that emit significant quantities of air pollutants in

areas of the country where National Ambient Air Quality Standards (NAAQS) are not being attained.

Annual nationwide VOC emissions from vegetable oil plants are estimated to be 72,000 megagrams (79,000 tons). This represents about 0.3 percent of total VOC emissions from stationary sources. Annual uncontrolled VOC emissions from a typical 1000 ton per day soybean oil plant range from 605 to 2420 Mg (665 to 2660 tons).

1.2 SOURCES AND CONTROL OF VOLATILE ORGANIC EMISSIONS FROM VEGETABLE OIL PLANTS

Two major sources in vegetable oil plants are recommended for control in this document: the extractor and the post desolventizer vents.

1.2.1 Extractor

The largest single source of VOC emissions in vegetable oil plants is the extractor. It is estimated that 50 to 75 percent of the emissions from vegetable oil plants are lost from the extractor if the extractor vent (main vent) is controlled with only a chilled water condenser. Extractor emissions (mostly hexane) can be reduced 90 to 95 percent with a properly designed and operated mineral oil scrubber (MOS) installed after the condenser on the main vent. For a typical 1000 ton per day soybean plant, uncontrolled emissions from the main vent are 5.4 Mg/day (5.9 tons/day), but only 0.5 Mg/day (0.6 tons/day) with a MOS. With the application of reasonably available control technology the hexane concentration should not exceed 9000 ppm prior to any dilution or bleed air stream. To ensure that dilution does not occur the maximum flow rate should not exceed 200 cf/MFC at 66^{o} and 1 atm.

The total capital investment for installing a MOS on a 640 Mg/day (700 ton/day) plant is $70,000. Total annualized cost for controlling and monitoring the same plant, including operation, maintenance, etc., is $26,600 (excluding recovered solvent credits). Credits for recovered solvent will more than offset these costs.

1.2.2 Post-Desolventizer Vents

Another 11 to 32 percent of VOC emissions are lost from the post-desolventizer vents. This includes emissions from the desolventizer, dryer, cooler, and pneumatic conveyor.

If proper desolventizer operation and maintenance practices are used, the hexane content of the meal exiting the desolventizer-toaster can be reduced to below 1350 ppm. Since residual hexane will be lost in the dryer, cooler, pneumatic conveyor, and final meal preparation areas, reducing the hexane content of the meal curbs emissions from these sources. It is believed that many plants are already achieving the 1350 ppm level.

Costs for desolventizer modifications and proper maintenance will vary from plant to plant. In cases where the desolventizer cannot be modified to keep hexane content below 1350 ppm in the exit stream, replacement with a new desolventizer is a control option. The total capital investment for replacing the desolventizer on a 640 Mg/day (700 ton/day) soybean plant is $468,000. Total annualized costs for the same plant are $103,100, not including solvent credits. Credits for recovered solvent will more than offset these costs. The resulting cost effectiveness is a credit of $0.05 per kilogram of solvent emissions controlled.

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* MFC Megagrams of extractor feed cake
TFC Tons of extractor feed cake

1.2.3 Other Sources

The emission levels presented herein are based on engineering calculations. Further verification of these emission levels will be made upon review of EPA emission tests being performed in conjunction with New Source Performance Standard development.

Fugitive emissions, which may be substantial, are not addressed in this document. They can be minimized by good housekeeping and maintenance practices.

1.3 COMPLIANCE AND MONITORING

It is recommended that weekly checks of the main vent stack and the meal leaving the desolventizer-toaster be made for one year. The data should be reviewed at that time and the monitoring frequency adjusted as necessary.

2.0 SOURCES AND TYPES OF VOLATILE ORGANIC EMISSIONS

The manufacture of vegetable oil from seed generally involves seed preparation, oil extraction, oil refining, and, in the case of solvent extraction, desolventization and treatment of the desolventized flakes. These processes account for potential emissions of several organic compounds: hexane solvent used in the extraction process; deodorizers used in heat exchangers; fatty acids removed from the vegetable oil; miscella (the mixture of solvent and oil); and the vegetable oil itself. The hexane solvent is a mixture of volatile organic compounds (VOC) which are photochemically reactive, i.e. under favorable atmospheric conditions they participate in photochemical reactions to form oxidants.

In the United States, nearly all vegetable oil is extracted from one of four seeds: soybeans, cotton, corn, or peanuts. Each type of seed varies with regard to oil content, meal content, and the amount of the seed actually fed to the extractor, i.e. 25 percent of a given quantity of peanuts (the hulls) is separated from the process prior to solvent extraction.*

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* Capacity is stated differently from operator to operator. Some base it on the total weight of cleaned raw seeds processed, others use the total weight of conditioned seed or the weight of conditioned seed actually put into the extractor. For the purposes of this report, plant capacity is always stated in megagrams of conditioned seed fed into the extractor. This conditioned seed is referred to as "extractor feed cake" or "seeds processed." Thus a 182-Mg/day (200-ton/day) plant that processes soybeans would handle 182 Mg/day (200 tons/day) of cleaned raw seeds and would feed that amount of soybean seed into the extractor.

Thus, emissions of VOC vary according to the raw material and type of extraction plant, as well as according to the condition and operation of the plant equipment. As is seen from Figure 2-1, the major VOC emission sources are the extraction and desolventization facilities. This document concentrates on these facilities. VOC emissions based on raw seed input are shown in Table 2-1. Since not all the raw seed is always fed into the extractor, emissions are based on 0.91 megagrams of feedcake (MFC), or one ton of feedcake (TFC) fed to the extractor in cottonseed, soybean, corn, and peanut oil plants. Estimated emissions are shown in Table 2-2.

Since soybean oil represents more than 80 percent of the oil produced, this document will be directed toward soybean oil extraction. Figure 2-2 shows a typical process flow diagram and material balance for the hexane solvent used for processing 0.91 Mg (1 ton) of soybeans. This may be considered a reasonably well operated plant, having overall uncontrolled solvent losses of 8 kg/MFC (16 lb/TFC). Overall losses decrease to an average of 2.6 kg/MFC (5.3 lb/TFC) when the main vent is ducted to an absorber. New plant contractors are currently guaranteeing overall solvent losses under strictly controlled conditions of less than 1.5 kg/MFC (3 lb/TFC) for soybean plants, and it has been reported that some plants have losses as low as 1 kg/MFC (2 lb/TFC).[1]

The processes and equipment used to manufacture vegetable oil are generally the same regardless of the type of seed being processed. The major manufacturing divergencies are prepressing and miscella refining.

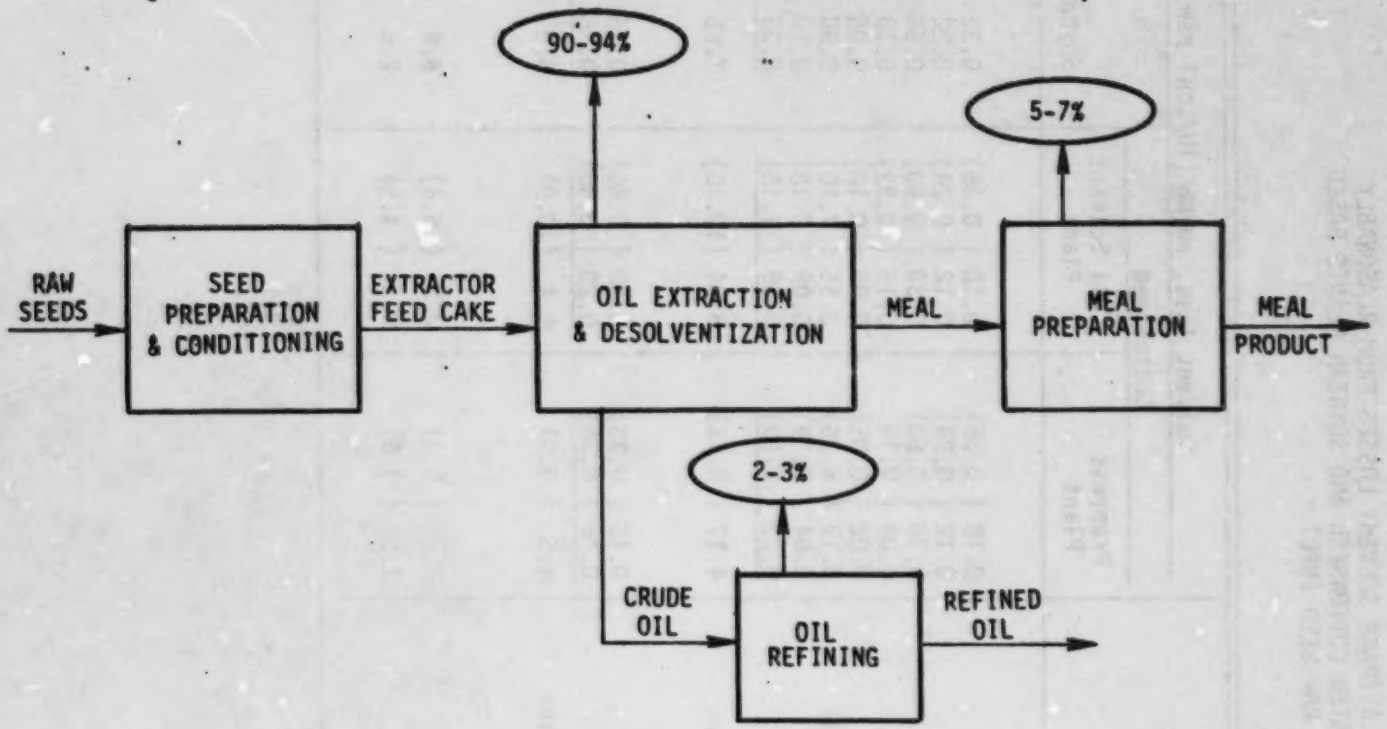

Figure 2-1. Relative uncontrolled hexane emission from vegetable oil extraction and related processes.

TABLE 2-1. ESTIMATED AVERAGE SOLVENT LOSSES FROM REASONABLY WELL-OPERATED COTTONSEED AND SOYBEAN PLANTS BASED ON CLEAN, RAW SEED INPUT *

Point of solvent loss	Solvent loss, kg/Mg (lb/ton) raw seed		
	Cottonseed		
	Prepress Plant	Full Solvent Plant	Soybeans
A. Operational losses			
Meal drying	0.18 (0.36)	0.18 (0.36)	0.32 (0.65)
Meal cooling	0.12 (0.24)	0.12 (0.24)	0.22 (0.45)
Meal product	0.30 (0.60)	0.30 (0.60)	0.55 (1.10)
Oil	0.08 (0.16	0.16 (0.32)	0.18 (0.36)
Waste water	0.02 (0.05)	0.05 (0.10)	0.05 (0.10)
Main vent (uncontrolled)	3.13 (6.26)	3.55 (7.10)	5.90 (11.80)
Solvent storage	0.04 (0.09)	0.09 (0.18)	0.10 (0.20)
Fugitive (leaks)	0.30 (0.59)	0.59 (1.18)	0.33 (0.66)
Total Operational Losses	4.17 (8.35)	5.04 (10.10)	7.65 (15.32)
B. Non-operational losses			
Start-up & Shutdown	0.18 (0.35)	0.20 (0.40)	0.16 (0.33)
Downtime	0.18 (0.35)	0.20 (0.40)	0.16 (0.33)
Total uncontrolled losses (rounded)	4.5 (9.0)	5.4 (10.9)	8.0 (16.0)
Less solvent collected in absorber (average)	2.7 (5.4)	3.2 (6.4)	5.4 (10.7)
Total controlled losses	1.8 (3.6)	2.2 (4.5)	2.6 (5.3)

* See Appendix A

TABLE 2-2. ESTIMATED AVERAGE SOLVENT LOSSES PER MEGAGRAM OF EXTRACTOR FEED CAKE FROM REASONABLY WELL-OPERATED VEGETABLE OIL PLANTS

Source of Loss	Solvent Losses, kg/MFC (lb/TFC)					
	Cottonseed		Soybeans	Corn		Peanuts
	Prepress	Full solvent		Prepress	Full Solvent	Prepress
Meal drying	0.28 (0.55)	0.32 (0.65)	0.32 (0.65)	0.32 (0.65)	0.20 (0.40)	.28 (0.30)
Meal cooling	0.20 (0.40)	0.22 (0.45)	0.22 (0.45)	0.20 (0.40)	0.12 (0.25)	.20 (0.20)
Meal product	0.48 (0.95)	0.55 (1.10)	0.55 (1.10)	0.52 (1.05)	0.32 (0.65)	.48 (0.50)
Oil	0.15 (0.30)	0.27 (0.54)	0.18 (0.36)	0.20 (0.40)	0.50 (1.00)	.20 (1.20)
Wastewater	0.04 (0.08)	0.08 (0.15)	0.05 (0.10)	0.05 (0.10)	0.14 (0.28)	.04 (0.33)
Main vent (uncontrolled)	5.90 (11.80)	5.90 (11.80)	5.90 (11.80)	5.90 (11.80)	5.90 (11.80)	5.90 (11.80)
Solvent storage	0.09 (0.18)	0.15 (0.30)	0.10 (0.20)	0.11 (0.22)	0.28 (0.55)	.09 (0.67)
Fugitive	0.55 (1.10)	0.99 (1.98)	0.33 (0.66)	0.74 (1.47)	1.88 (3.77)	.55 (4.40)
Start-up & Shutdown	0.33 (0.66)	0.33 (0.66)	0.16 (0.33)	0.33 (0.66)	0.33 (0.66)	.33 (0.66)
Downtime	0.33 (0.66)	0.33 (0.66)	0.16 (0.33)	0.33 (0.66)	0.33 (0.66)	.33 (0.66)
Total uncontrolled losses (rounded)	8.4 (16.7)	9.1 (18.3)	8.0 (16.0)	8.7 (17.4)	10.0 (20.0)	8.4 (20.7)
Less solvent collected in absorber (average)	5.4 (10.7)	5.4 (10.7)	5.4 (10.7)	5.4 (10.7)	5.4 (10.7)	5.4 (10.7)
Controlled loss MFC (TSP)	3.0 (6.0)	3.7 (9.6)	2.6 (5.3)	3.3 (6.7)	4.6 (9.3)	3.0 (10.0)

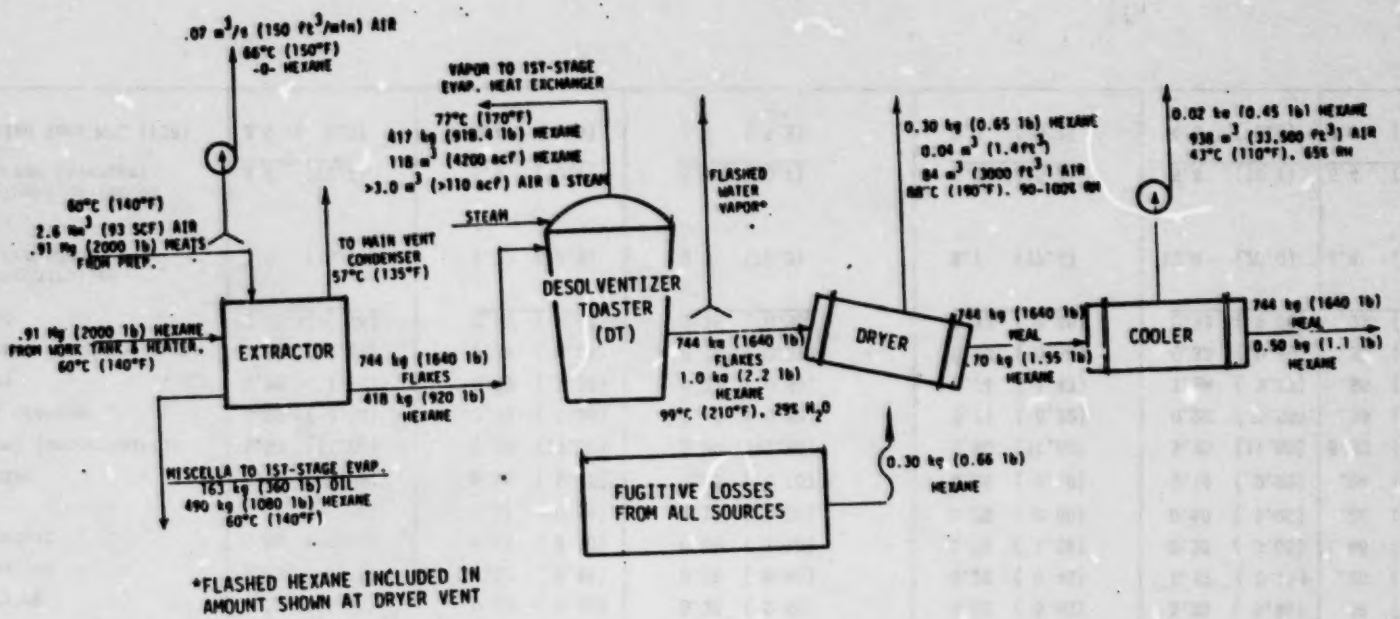
.07 m³/s (150 ft³/min) AIR
66°C (150°F)
-0- HEXANE
VAPOR TO 1ST-STAGE EVAP. HEAT EXCHANGER
77°C (170°F)
417 kg (918.4 lb) HEXANE
118 m³ (4200 acf) HEXANE
>3.0 m³ (>110 acf) AIR & STEAM
60°C (140°F)
2.6 Nm³ (93 SCF) AIR
.91 Mg (2000 lb) MEATS FROM PREP.
TO MAIN VENT CONDENSER 57°C (135°F)
STEAM
DESOLVENTIZER TOASTER (DT)
FLASHED WATER VAPOR*
0.30 kg (0.65 lb) HEXANE
0.04 m³ (1.4ft³)
84 m³ (3000 ft³) AIR
88°C (190°F), 90-100% RH
0.02 kg (0.45 lb) HEXANE
938 m³ (33,500 ft³) AIR
43°C (110°F), 65% RH
.91 Mg (2000 lb) HEXANE FROM WORK TANK & HEATER, 60°C (140°F)
EXTRACTOR
744 kg (1640 lb) FLAKES
418 kg (920 lb) HEXANE
744 kg (1640 lb) FLAKES
1.0 kg (2.2 lb) HEXANE
99°C (210°F), 29% H2O
DRYER
744 kg (1640 lb) MEAL
70 kg (1.55 lb) HEXANE
COOLER
744 kg (1640 lb) MEAL
0.50 kg (1.1 lb) HEXANE
MISCELLA TO 1ST-STAGE EVAP.
163 kg (360 lb) OIL
490 kg (1080 lb) HEXANE
60°C (140°F)
FUGITIVE LOSSES FROM ALL SOURCES
0.30 kg (0.66 lb) HEXANE
*FLASHED HEXANE INCLUDED IN AMOUNT SHOWN AT DRYER VENT

Figure 2-2. Typical process flow diagram for soybean plant without a control device on its main vent.

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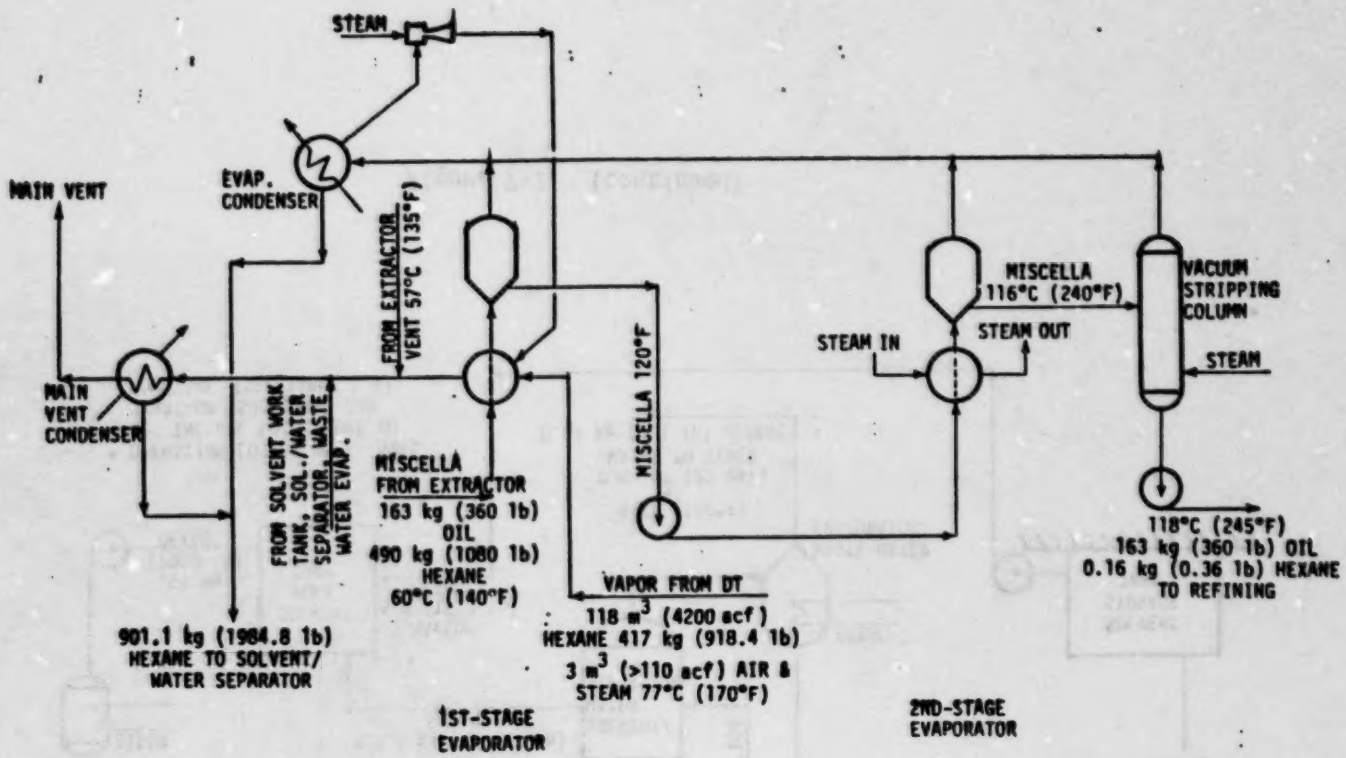

Figure 2-2. (continued)

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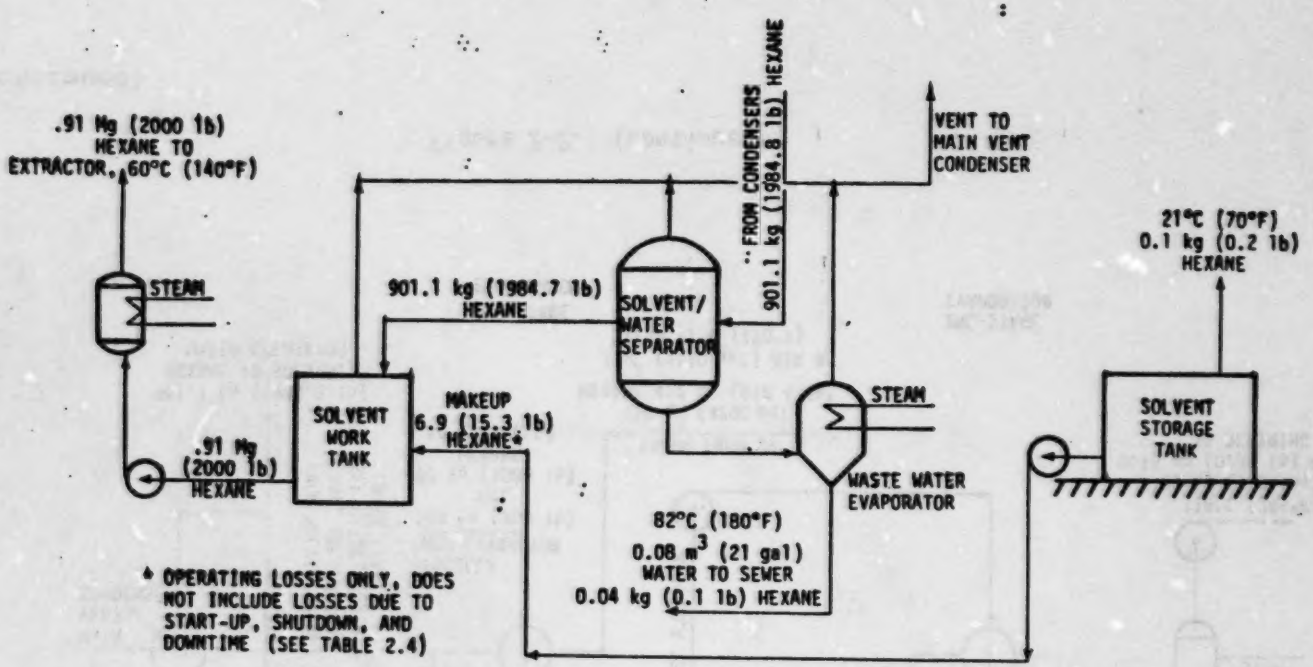

Figure 2-2. (continued)

2.1 SEED PREPARATION AND CONDITIONING

The first step in processing oil seed is to screen out foreign material such as sticks, stones, leaves, sand, and dirt. Tramp iron is removed by permanent magnets or electromagnets mounted above the seed conveyor. The seed is generally cleaned and dried before being stored, and moisture content kept low to prevent heating and microbial spoilage.

Before oil separation, the seed must be cracked and completely or partially hulled (decortication) using a combination of air classification and screening, or in some cases, flotation. The hulls of most oil-bearing seeds contain as little as one percent oil. If they are not removed before extraction, they will reduce the total yield by both adsorbing and by retaining oil in the press cake, reducing equipment capacity.

Two basic types of hulling machines are used: the bar and the disc huller. Both are ideal for seeds with loose or flexible hulls, such as cottonseed, peanuts, sunflower seed, etc. The essential component of the bar huller is a cylinder with square-edged knives ("bars") arranged longitudinally. This device rotates inside a stationary cylinder, similarly equipped with knives. Seed is fed between the cylinders, where the hulls are split by the opposed cutting edges.

The disc huller is similar in principle, except that the cutting edges consist of radial grooves in the surface of two opposed, vertically mounted discs, one of which rotates. Seed is fed to the center of the disc; the hulled products are discharged by centrifugal force at the periphery.

Cottonseed kernels or those with meats that adhere to the hull after separation must pass through a type of hammer mill called a hull beater. The following separation system is commonly used after the hulling of cottonseed.

1. Screening of large meat particles from hulls and uncut seed.
2. Separation of hulls from uncut seed by an air lift.
3. Separation of small meat particles from hulls by hull beating and screening.
4. Separation of hull particles from meats by air lift.
5. Recycling of uncut seed to the hulling machine.

Soybeans are usually dehulled by cracking the beans on cracking rolls, and then separating hulls and kernels. Each cracking roll has two pairs of rolls approximately 30 cm (12 in.) in diameter and 130 cm (50 in.) long and is capable of cracking 450 Mg/day (500 ton/day) of soybeans. Uncracked beans are returned to the cracking rolls, while the kernels are fed to a deck of fine-mesh screens. Hulls that contain kernel particles undergo air separation, using a gravity table to separate the light hulls from the heavier kernels.

Next, the seeds (or meats) are steam cooked to soften the meats so a good quality, workable flake can be formed in subsequent operations.

Oil seed is generally cooked on a continuous basis in "stack cookers." Cooking time may vary from 30 to 120 minutes, depending on the nature and geometry of the seed. The temperature of the seed leaving the cooker ranges from 60^{o} to $99^{o}C$ (140^{o} to $210^{o}F$).

Horizontal-jacketed tubes, or "conditioners," can serve the same purpose as stack cookers. In general, however, these units are more commonly used in conjunction with stack cookers rather than as a substitute for them. There are no VOC emissions from this process.

In prepress plants (plants mechanically removing a portion of the oil prior to solvent extraction), the seeds are next conveyed to continuous screw presses where a portion of the oil is removed. If screw pressing is the only extractive process involved, then the press cake is processed at much greater pressure, so that the emerging product has a residual oil content of only four to six percent. These percentages increase for certain seed types and older presses.

Continuous screw presses ("expellers") are used to the almost complete exclusion of batch hydraulic presses for both mechanical extraction and prepressing prior to solvent extraction. Continuous presses used for oil seed in the United States are mostly high-pressure machines designed to effect oil recovery in one step. The same machines

can also be used for prepressing before solvent extraction. For this purpose, however, machines specially designed or modified for low-pressure operation have proved more satisfactory.

Prepressing removes much of the oil from the seeds before solvent extraction, minimizing the size of the solvent extraction plant needed. Prepressing produces a meal with a high-protein quality and maximizes the overall oil yield.

In full solvent plants (plants exclusively utilizing solvent extraction to produce oil), conditioned seeds are conveyed from the conditioners to the flaking rolls. Flaking rolls are essential in the preparation of oil seeds for continuous solvent extraction since the extraction rate is strongly inversely proportional to the flake thickness.

2.2 CONVEYING FLAKES TO THE EXTRACTOR

The flakes are conveyed from the flaking rolls or the screw press to the extractor in a mass-flow type of enclosed conveyor. This is the conveyor into which the solids from the flaking roll aspirator are discharged. Figure 2-2 shows the aspiration air from the flake conveyor discharging to the atmosphere. This aspiration serves two purposes. It removes free moisture in the flakes and prevents any solvent vapors that may escape through the extractor flake inlet from getting into the

bean preparation area. The latter is a safety precaution. Solvent emissions from this aspiration point are generally detectable only during start-up and shutdown.[2] This aspiration exhaust vent generally has a volume of approximately 0.07 m^3/s (150 ft^3/min) regardless of plant size.[3] The VOC emissions from the aspiration vent are included in the solvent losses due to shutdown and start-up in Table 2-1.

2.3 SOLVENT EXTRACTION OF THE OIL

Solvent extraction is the most efficient method of recovering oil from almost any oil-bearing vegetable seed. Extraction is accomplished in a countercurrent procedure, in which intimate contact is achieved between the oil-bearing seed and the solvent. The two problems involved in this process are that complete extraction can be accomplished only by the use of a large volume of solvent relative to the volume of oil extracted, and that the solvent must later be separated and recovered from the oil. These problems represent a substantial portion of the overall plant operating cost. A prime objective in modern solvent extraction is to reduce the solvent-to-oil ratio yet still maintain a high oil yield. In most efficient continuous extraction plants, the solvent-oil ratio is as low as five or six to one on a weight basis. In order to obtain this ratio, a certain amount of oil is left in the meal. The accepted practice is to reduce the oil content of the meal to less than one percent, preferably 0.5 percent.

The most common solvent used in commercial continuous edible oil extraction systems is a hexane-type naphtha boiling at 63° to 69° C. (146° to 156° F). Other solvents that can be used include a pentane-type with an ASTM boiling range of 31° to 36°C (88° to 97°F), and a heptane-type with a boiling range from 90° to 100°C (194° to 212°F). Hexane solvent is the most widely used for oil seed, although heptane is also suitable for use in most modern plants. Pentane is used only in the extraction of heat-sensitive oils, such as those needed for pharmaceuticals.

Extractor Types

Two types of continuous solvent extractors predominate, the vertically-arranged basket type and the rotary cell type. A continuous shallow bed rectangular loop extractor having no baskets or cells has also found use in the industry.

The basket-type extractor (Figure 2-3) resembles an enclosed bucket elevator. With this unit, oil is extracted by percolating solvent through seed flakes contained in a series of baskets with perforated bottoms. To ensure uniform percolation and drainage, the width and depth of the baskets are fixed, but the length is varied in order to obtain the desired capacity. About 40 baskets are supported on an endless chain within a gas-tight housing. Flaked oil seed is screw-conveyed into a charging hopper at the top of the extractor housing. From the hopper, the seed passes through a filled conveyor tube that serves as a seal against solvent vapor inside the extractor. The baskets pass continuously under the tube at about one revolution an hour. As each basket passes below the tube and starts down the descending side of the extractor, it is charged automatically from the seed hopper.

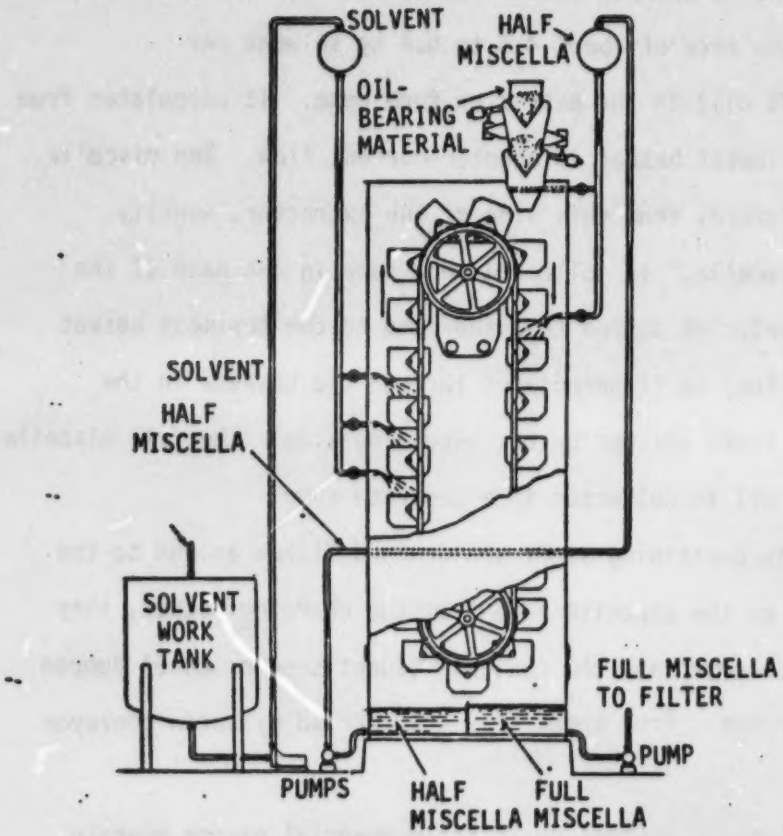

Figure 2-3. Enclosed basket extractor.

Extraction is accomplished by the percolation of solvent through the seed baskets during their passage down the extractor and back up again. Fresh solvent is sprayed into a basket near the top of the ascending line at the rate of about 4.6 to 5.4 kg solvent per kg oil (5 to 6 lb/lb oil) in the extractor feed cake. It percolates from the highest to the lowest basket in counter-current flow. The miscella (solvent and oil mixture) from this side of the extractor, usually termed the "half miscella," is collected in a sump in the base of the housing. Half miscella is pumped from the sump to the top-most basket of the descending line, so it percolates through the baskets in the same manner as the fresh solvent on the ascending side. The full miscella containing all the oil is collected in a separate sump.

As the baskets containing spent and drained flakes ascend to the top of the housing on the opposite side from the charging hopper, they are automatically inverted and the contents (spent seed or cake) dumped into a discharge hopper. From there they are carried by screw conveyor to the meal dryers.

Most basket-type extractors built for commercial plants operate at capacities ranging from 180 to 9.0 Mg (200 to 1000 tons) of flakes per day.

The rotary cell extractor is similar in principle to the basket extractor, except that the baskets move in a rotary motion through a horizontal plane. The miscella percolating through the baskets falls into separated compartments in the bottom of the extractor housing. From these compartments, or sumps, it is recycled by a series of pumps to the top of the seed-filled baskets.

Rectangular loop extractors vary from vertical and rotary extractors in several ways. First, the rectangular loop extractor processes the flakes continuously along a conveyor chain rather than in baskets. Secondly, a stationary, linear, vee-bar screen and a cyclone separator are used on the full miscella instead of filters or screens. Discharge of flakes and miscella is continuous.

Extractors are vented to the main vent condenser. Negative pressure removes air from the system, cutting solvent losses.

After extraction, the spent cake (containing approximately 35 to 40 percent solvent) is conveyed by a vapor-tight conveyor to the desolventizer. Modern desolventizers also toast the flakes for purposes of producing a product meal of higher quality. This piece of equipment is known as a desolventizer-toaster. Negligible solvent emissions are vented to the atmosphere directly from the desolventizer-toaster.

2.4 SOLVENT/OIL SEPARATION

After extraction, oil and solvent are separated by distillation. Extracted oil is usually combined with press oil before being refined. In order to preserve the quality of the virgin press, however, this stage is sometimes eliminated, as is the case with olive oil.

From the extractor sump, miscella containing oil, solvent and suspended solids is filtered on a continuous basis before distillation. The amount of suspended solids varies depending on the oil seed. After filtration the miscella is preheated in a heat exchanger

(to which heat is often provided by the desolventizer-toaster and spent steam from the steam ejector vacuum system), and then it passes through rising film or falling film evaporators. Approximately 90 to 95 percent of the solvent is evaporated in the first-stage and second-stage evaporators, condensed and collected for reuse. Oil effluent from the evaporator then passes to a vacuum distillation column, where most of the remaining 5 to 10 percent of solvent is steam-stripped from the oil. The temperatures and pressures at which the distillation system is operated vary according to the nature of the oil and solvent. Oil from the bottom of the distillation column is cooled and collected for refining. Overhead vapor containing residual solvent is condensed, collected, and decanted along with the solvent condensate from the evaporator. This solvent is then mixed with fresh makeup solvent and recycled to the extraction system. Operating losses from this loop of the process leave the system through the main vent stack. This contributes only a small portion of the total amount of hexane in that exhaust stream, however. Makeup solvent is also required as a result of fugitive losses due to system leaks, retention of solvent in the crude oil, and retention of solvent in the discharged wastewater.

Estimated fugitive losses from reasonably well-operated soybean oil plants range from 0.33 kg/MFC (0.66 lb/TFC) for large plants to 0.85 kg/MFC (1.7 lb/TFC) for smaller plants of less than 910 Mg/day (1000 tons/day) capacity. Fugitive emissions from cottonseed, corn, and peanut plants range from 0.6 to 1.8 kg/MFC (1.1 to 3.8 lb/TFC) as shown in Table 2-2. These estimates may change as more data become available.

Fugitive losses are not directly proportional to plant size.[4] This is understandable since, for example, a large pump has less seal area per gallon handled than a small pump. One source estimates fugitive losses to be 3 to 5 times larger in small plants than in large plants.[5]

Solvent content of the crude oil is governed by commercial practice. If it is too high, storage of the crude oil presents a safety hazard. The oil is subjected to a flash or "pop" test to determine that its solvent content is within accepted limits. It must have a closed-cup flash point in excess of 250°C (482°F). The volatile content of crude oil is limited to 0.2 percent. Approximately 0.1 percent is solvent in the form of miscella.

2.5 SOLVENT/MEAL SEPARATION

Oil seed flakes leave the extractor saturated with solvent. In order to reclaim the solvent and make the meal edible, the flakes are fed to a desolventizer toaster. This device is similar to a stack cooker in which live or indirect steam is used to vaporize and strip out occluded solvent. In addition to vaporizing most of the solvent, the steam also adds moisture to the meal, thus minimizing dust carryover to the solvent condenser.

Older plants use a device called a "Schneckens," for removal of solvent. It consists of a series of horizontal, steam-jacketed tubes, through which the flakes are propelled by screws. Another method of desolventizing is to pass superheated solvent vapors through the meal. Most large modern plants desolventize with a desolventizer-toaster. This is a critical piece of equipment in the plant from a solvent-loss standpoint since the meal is a major source of solvent loss. If the desolventizer-toaster is new and operated efficiently, meal can leave it containing as little as 500 ppm solvent.[6]

This is only 0.41 kg solvent/MFC (0.82 lb solvent/TFC) for soybeans. Inefficient desolventizers may allow solvent retention to remain as high as 3.5 kg/MFC (7 lb/TFC). The solvent content of this meal is most important since all the occluded solvent from this point on is lost. At an average plant, approximately 50 percent of the residual solvent is thought to be exhausted in the dryer and cooler.[7] A poorly operated desolventizer, leaving a higher amount of occluded solvent, will cause proportionately higher emissions from the dryer and cooler. Both the dryer and cooler require air for proper operation. Vent gas volumes are approximately 92 m^3/MFC (3000 ft^3/TFC) for the dryer and 1032 m^3/MFC (33,500 ft^3/TFC) for the cooler.[8] The National Soybean Processors Association estimates dryer gas volumes to be 300-460 m^3/MFC (10,000-15,000 ft^3/TFC). The meal discharges from the desolventizer-toaster at a temperature above the boiling point of water. This causes the moisture in the meal (18 to 22 percent) to flash. A hood and a natural draft stack are sometimes provided to carry the moisture away. Assuming that as much as one-tenth of the moisture flashes off, volumes in this vent are generally less than 0.05 m^3/s (100 ft^3/min) for cottonseed, corn, and peanut plants. Soybean plants have somewhat larger volumes, ranging from 0.09 to 1.4 m^3/s (200 to 3000 ft^3/min) for a 180-Mg/day (200-ton/day) and 2730-Mg (3000-ton/day) plant respectively. The solvent content of this exhaust is unknown; however, it is expected to be a small quantity relative to the dryer and cooler vents.

Small plants very often dry the desolventized flakes in the desolventizer-toaster itself and then pneumatically convey them to the feed conditioning facility. The pneumatic conveyor cools the meal sufficiently to eliminate the need for a cooler. In short, some plants have no aspirator, dryer, or cooler. These plants emit hexane from the pneumatic conveyor vent.

Since the final meal product is tested for solvent content by means of a "flash" or "pop" test, it is probable that the solvent content of the final meal product is a maximum of 700 to 1200 ppm, regardless of the desolventizer efficiency. For soybean meal product (not post-desolventizer, post-dryer and cooler) solvent content ranges from 200 to 700 ppm or 0.17 to 0.56 kg/MFC (0.33 to 1.1 lb/TFC). The seed acts as an adsorbent; thus reduction in solvent content below the 200 to 700 ppm level is unlikely once it leaves the desolventizer-toaster.

In summary, the solvent remaining in the meal after the desolventizer-toaster is ultimately lost to the atmosphere. A reasonably well-operated desolventizer-toaster discharges meal with an average solvent content of about 1350 ppm.[9,10] Solvent losses per given weight of extractor feed cake vary according to the amount of meal produced.

About 50 percent of the meal-entrained solvent is vented to the atmosphere through the post-desolventizing vents--the dryer and cooler vents, or the pneumatic conveyor vent. The balance of the solvent remains in the meal. The remaining solvent is probably lost as a fugitive emission during the meal processing and marketing operations. Industry spokesmen state that solvent odors are undetectable during meal processing and storage. This is probably due to the low temperatures at which these operations are carried out, the adsorbent quality of the seed, and the lowering of the solvent's vapor pressure as a result of its mixing with the retained oil in the meal.

2.6 CRUDE OIL PROCESSING

The crude oil is normally shipped to another establishment for further processing. The occluded solvent (0.1 percent maximum) is in a miscella form and has a vapor pressure of less than 1 mm Hg. Subsequent processing at elevated temperatures will drive off some of this solvent. Industry spokesmen, however, are not aware of any detectable solvent vapors from the crude oil. This is a concern where the oil is stored, since high solvent content could cause storage tank top vapors and vent vapors to exceed the lower explosive limit (LEL) for hexane.

Crude oil is refined, bleached, hydrogenated, and deodorized. None of the exhausts or vents from these operations are controlled for solvent emissions. Assuming all the occluded solvent is driven off in the refining and bleaching processes, maximum emissions are approximately 1.0 kg/Mg of oil (2.0 lb/ton of oil). For a soybean oil plant which yields 179 kg of oil per MFC this represents 2 to 3 percent of the total solvent loss.

2.6.1 Refining

The primary object of refining vegetable oil is to neutralize and remove free fatty acids. The most important and widely used method is to treat the oil with an alkali, such as caustic soda. Free fatty acids, along with other acidic substances, combine with the alkali and are converted into oil-insoluble soaps. Alkali treatment also produces a decolorizing action, affecting those substances that become oil insoluble on hydration. Caustic soda has the disadvantage of saponifying a small proportion of the neutral oil, in addition to reacting with free fatty acids. For this reason other alkalies, such as soda ash or sodium bicarbonate, are used in some refining operations.

Another method of refining is steam stripping. Since fatty acids are more volatile than glycerides, it is possible to distill them off at reduced pressures and elevated temperatures. Liquid-liquid extraction has been also used to some extent. The oil is intimately combined with an immiscible solvent in a countercurrent operation, whereupon the free fatty acid mass transfers from the oil phase to the solvent phase.

Acid refining is used for some oils, particularly those included in paint. The oil is treated with strong sulfuric acid. This process does not reduce free fatty acids, but it clears and precipitates phosphatides and other similar impurities.

2.6.2 Bleaching of Vegetable Oils

The standard method of bleaching is to adsorb color bodies from the oil onto the surface of activated carbon or clay earth.

In order to avoid the harmful effects of oxidation, the oil is generally bleached under vacuum on a continuous basis. Several similar bleaching processes using an adsorbant (earth) slurry with oil are available. Most continuous bleaching processes use multiple-leaf filters so slurry can be switched to a clean filter when the onstream filter is saturated with clay. The recovery process generally consists of boiling the spent earth with a weak aklaline aqueous solution, then salting out and decanting off the resulting oil layer.

2.6.3 Hydrogenation of Vegetable Oils

In order to produce hard or plastic fats, or to enhance the oxidation stability of the oils (by lowering the polyunsaturated acid content), edible oils are often partially hydrogenated. This process requires hydrogen under moderate pressure and a catalyst, usually reduced nickel. The reaction involves breaking specific carbon-carbon double bonds on the triglyceride molecule, and their conversion to a single bond by the addition of hydrogen.

2.6.4 Deodorization

Bleached and hydrogenated oils often give off odors, caused by aldehydes or other slightly volatile materials. These oils are deodorized by steam distillation (stripping) under high vacuum at temperatures between 204° and 260°C (400° and 500°F).

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3.0 APPLICABLE SYSTEMS OF SOLVENT EMISSION REDUCTION

3.1 INTRODUCTION

Estimated VOC emissions from the solvent extraction and refining of vegetable oils during 1977 amount to 71,830 Mg (78,900 tons). Domestic vegetable oil supplies for the year 1976/1977 approached 5.4×10^6 Mg (6×10^6 tons). Nearly 75 percent of domestic production is soybean oil. Not all the remaining oil is solvent extracted; other methods are used to produce the oil. For example, in 1974 only 34 of the nation's 83 cottonseed oil mills used solvent extraction. However, these 34 mills extracted an estimated 60 to 70 percent of the nationally produced cottonseed oil. Estimated nationwide solvent losses for 1977 are as follows:

Soybeans	61,000 Mg	(67,000 tons)
Cottonseed	6,190 Mg	(6,800 tons)
Corn	2,090 Mg	(2,300 tons)
Peanuts	910 Mg	(1,000 tons)
Other	1,640 Mg	(1,800 tons)
	71,830 Mg	(78,900 tons)

Uncontrolled emissions would exceed 181,800 Mg (200,000 tons) for this industry. The only emission control methods employed by the industry are good operating practices, including equipment replacement and maintenance and use of absorbers or adsorbers on the main vent stack. Figure 2-1 indicates that nearly all the potential solvent losses occur during the extraction and

desolventization processes. Solvent emissions resulting from the meal preparation, oil refining, bleaching, hydrogeneration, and deodorizing facilities total only 6 to 10 percent of the total.

Economic and safety considerations dictate that hexane losses be minimized. Hexane currently costs approximately $150.50/m^3 ($0.60/gal). All plants use condensers on their main vent to limit emissions. This is a normal part of process operations and is not considered a control device. However, hexane losses from the condensers are considerable, resulting in high hexane replacement expenditures. Most plants have an absorber or adsorber downstream from the main vent condenser.[1]

In a vegetable oil plant, the major potential emission sources are the main vent, the post-desolventizing vents, and system leaks.

3.2 CONTROL OF SOLVENT LOSSES FROM THE MAIN VENT

The main vent gases exit the condenser saturated with hexane. This gas stream is typically on the order of 1.4 to 5.7 m^3/s (50 to 200 acfm), depending on plant size. Improper operation may draw air into the system, increasing the vapor flow rate. The condenser typically lowers the gas temperature to 38°C (100°F), or about 35 volume percent hexane. Very few plants operate condensers with chilled water. Even if the vent gases were lowered to 10°C (50°F), the hexane content would be about 10 volume percent. For a typical 910 Mg (1000 ton/day) soybean plant using chilled water condensers, losses would be of 1.1 Kg (2.5 lb) solvent per minute.

Mineral oil scrubbers (MOS) have been developed that are capable of reducing the hexane content of the main vent gases to less than 0.9 volume percent.[2,3] A schematic diagram of an MOS is shown in Figure 3-1. This control device can reduce potential emissions from this source by approximately 95

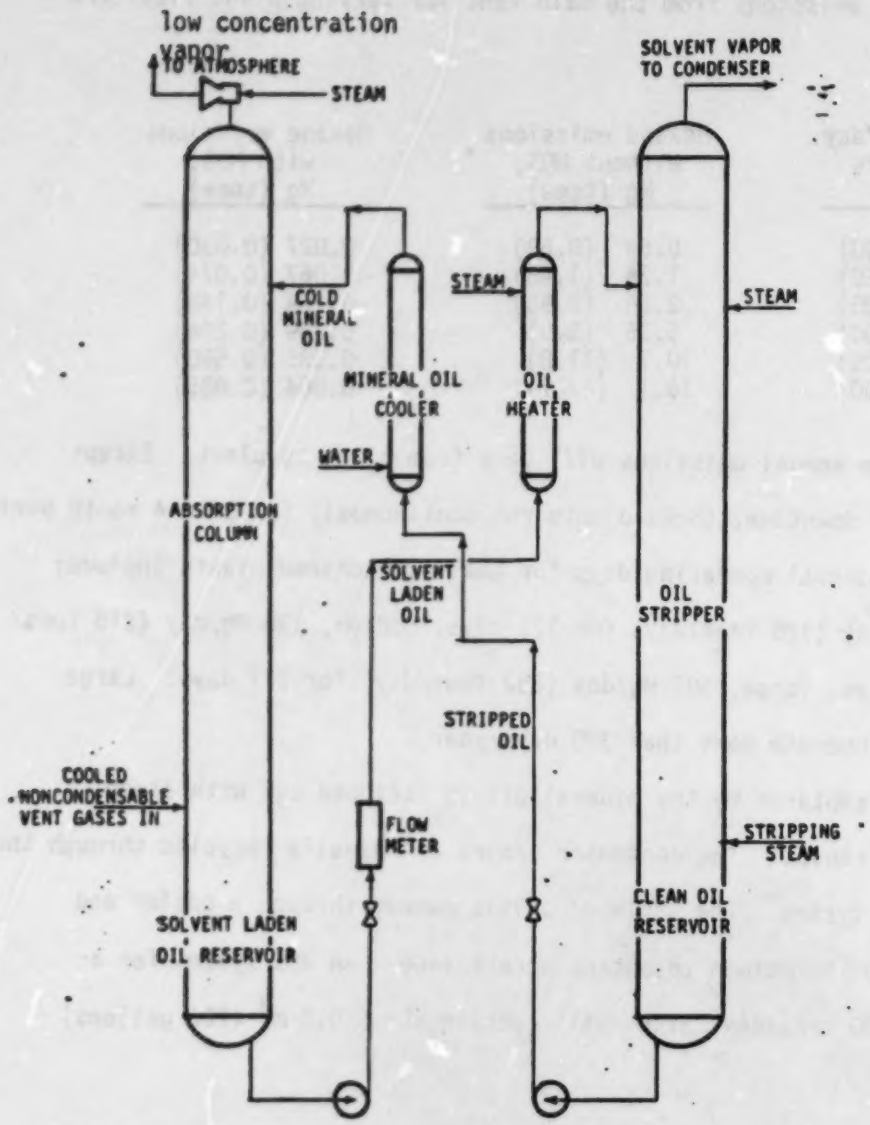


Figure 3-1. Schematic diagram of mineral oil scrubber.

percent. Daily emissions from the main vent for varying plant sizes are calculated as:

Plant size, Mg/day (tons/day) seeds processed	Hexane emissions without MOS, Mg (tons)	Hexane emissions with MOS, Mg (tons)
90 (100)	0.54 (0.59)	0.027 (0.030)
230 (250)	1.34 (1.48)	0.067 (0.074)
450 (500)	2.68 (2.95)	0.134 (0.148)
910 (1000)	5.36 (5.9)	0.269 (0.296)
1820 (2000)	10.7 (11.8)	0.536 (0.590)
2730 (3000)	16.1 (17.7)	0.804 (0.885)

The reduction in annual emissions will vary from plant to plant. Except for unscheduled downtime, these plants run continuously for 3 to 4 month periods. Representative annual operating days for small cottonseed plants include: small, 109 Mg/day (120 tons/day) for 172 days; medium, 196 Mg/day (216 tons/day) for 228 days; large, 502 Mg/day (552 tons/day) for 227 days. Large soybean plants operate more than 330 days/year.

The hexane captured by the mineral oil is stripped out with steam, condensed, and reused. The condenser vapors are usually recycled through the vapor recovery system. The stripped oil is pumped through a cooler and into the absorption column to absorb more hexane. An MOS system for a 910 Mg/day (1000 tons/day) plant will contain about 0.8 m^3 (200 gallons) of mineral oil.

3.3 CONTROL OF POST-DESOLVENTIZING VENTS

A portion of the solvent retained in the desolventized flakes is evaporated in the dryer and cooler and vented to the atmosphere. Some portion of the remainder is lost in the meal preparation processes.

Because of the adsorbing nature of the seed, the latter is believed to be a small amount and cannot be controlled easily. Figure 3-2 shows the estimated losses from a reasonably well-operated soybean plant which has a drying and a cooling facility. Maximum removal is dependent on proper equipment operation, adequate stripping steam, and equipment maintenance.

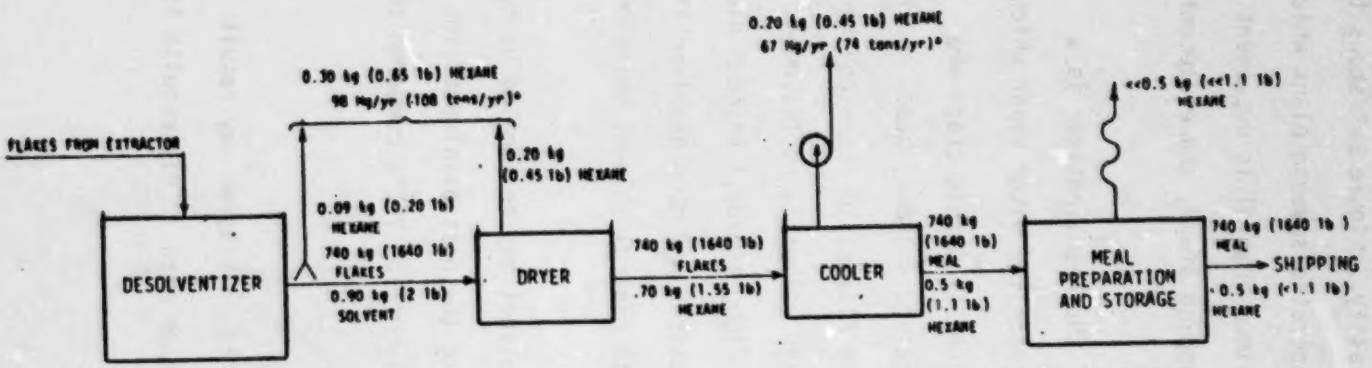
The aspiration vent on the outlet of the desolventizer is a natural draft stack. Its purpose is to catch the water vapor which flashes off the hot meal. Solvent emissions from this stack are estimated at 10 percent of the total entrained solvent, based on the assumption that 10 percent of the moisture flashes to steam and the solvent flash is proportional. Exhaust gas volume is estimated at 0.33 m^3/s (700 ft^3/min) for a 910 Mg/day (1000 ton/day) soybean plant.

Other than using good operating practices and good desolventizing equipment, no attempt is presently made to control solvent emissions from the desolventized flakes or meal.

Emissions from the meal-entrained solvent may be limited by more efficient desolventizing or by controlling the post-desolventizing vents. The aspirator vent is a relatively small source of VOC's compared to the dryer and cooler vents.

3.3.1 Replace Desolventization Equipment

A faulty or poorly operated desolventizer-toaster may result in inadequate desolventization of the flakes or meal. This results in



* ANNUAL EMISSIONS BASED ON A 910-Mg/day (1000-tons/day) PLANT OPERATING 330 days/yr

Figure 3-2. Estimated solvent losses from meal preparation facilities of a reasonably well-operated soybean plant, based on 0.91 Mg (1 ton) of clean, raw soybeans.

higher VOC emissions from the dryer and cooler. Emission reductions may be achieved by modifying the desolventizing equipment to effect better operation. Replacement of desolventization equipment has the following advantages:

- reduced hexane loss
- increased product (meal) quality
- possible reduced steam consumption
- no adverse environmental impacts

Under good conditions, a new desolventizer-toaster can reduce meal solvent content to 500 ppm.[4,5] This concentration is considerably lower than the 1350 ppm found at a reasonably well-operated facility.[6,7] Estimated dryer and cooler solvent emissions from 910 Mg/day (1000 ton/day) soybean plant with a new desolventizer-toaster is 64 Mg/yr (70 tons/yr).

3.3.2 Add-On Controls for Post Desolventizing Vents

Add-on controls on the post desolventizing vents (dryer, cooler, and pneumatic conveyor vents) are another option to curb hexane emissions resulting from inefficient desolventization. Although heretofore unapplied to this source, carbon adsorption and incineration are considered acceptable control technology by the principle of technology transfer. The National Soybean Products Association has raised doubts regarding the safety of these control options.

Carbon Adsorption - Solvent emissions can be removed from these vents with a carbon bed adsorber for reuse in the extractor. Although no plants are known which control these sources at present, carbon bed

adsorbers are used on other high-volume hydrocarbon sources, including the main vent in some soybean plants.

Dryer vent gases are saturated with water at 88°C (190°F). Approximately 0.06 m^3 (2 ft^3) air is exhausted per 0.5 Kg (1 lb) of flakes. This gas stream is dusty and must be cleaned prior to entering an adsorber. Dilution air can be used to reduce the relative humidity sufficiently to vent the gases to a fabric filter and then to the carbon bed adsorber.

The volume of gases from the cooler is about 0.6 m^3 (20 ft^3) per 0.5 Kg (1 lb) of flakes. These gases have a relative humidity of about 65 percent at 43°C (110°F). They can be vented, without dilution, directly to the fabric filter and the adsorber.

It is not practical to combine the cooler and dryer vents, since the resulting relative humidity would be too high for the fabric filter.

Except for combustion products of fuel used to generate steam and electricity for the adsorber, no secondary pollutants are produced by this control device. The captured solvent is reused in the process. Carbon bed life is approximately five years.[8] When replaced, the old carbon is sent to a processor for reactivation and reuse. Thus, none of the activated carbon enters the solid waste stream. Carbon bed adsorbers, properly operated, can remove 95 percent of the hexane from the vent gases.[9] This reduces solvent emissions to a level well below that found in a reasonably well-operated facility.

Considerable fire hazard would exist if a desolventizer-toaster accidently dumped hexane-laden meal into the carbon adsorption equipped dryer.[10]

Incineration - Another method of reducing VOC emissions from the post-desolventization vents is to incinerate the exhaust gases. Incineration has been used successfully on hydrocarbon-containing exhausts in numerous other industries. It must be pointed out, however, that the cooler's low exhaust temperature and high gas volume tend to discourage this emission reduction technique. In addition to these problems, the National Fire Prevention Association (NFPA) presently does not recommend flaring of process vents because of the extreme flammability of hexane.[11] The NFPA Sectional Committee on Solvent Extractions is planning to propose a change in their safety bulletin wherein flares will be permitted for process vents, provided the flares are located more than 30 m (100 ft) from the extraction process and that approved devices are installed to prevent flashback in the vent piping.[12]

Incineration of vent gases can eliminate 99 percent of the VOC emissions from these facilities.

3.4 CONTROL OF FUGITIVE EMISSIONS

The VOC emissions resulting from liquid and gaseous leaks may be as high as 0.85 Kg/MFC (1.7 lb/TFC)[13] for a 910 Mg/day (1000 ton/day) soybean plant. These emissions can be reduced to 0.33 Kg/MFC (0.66 lb/TFC) in a reasonably well-operated plant. Since these losses result mainly from leaks and spills, control is best effected by an adequate maintenance and housekeeping program.

3.5 SUMMARY

Emissions of VOC from a reasonably well-operated 910 Mg/day (1000 ton/day) soybean plant approximate 8 Kg/MFC (16 lb/TFC) without a main vent control and 2.7 Kg/MFC (5.3 lb/TFC) with a control system on the main vent. Poorly operated plants may lose over 8 Kg/MFC (16 lb/TFC) even with a control device on the main vent.

Mineral oil scrubbers on the main vents can remove 95 percent of the solvent in that gas stream. Other emissions are limited by good operating practices and maintenance. The industry does not currently use control devices on the post-desolventizing vents. These gas streams could be controlled with carbon bed adsorbers or afterburners under the principle of technology transfer.

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4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Purpose

The purpose of this chapter is to present capital and annualized costs for alternative ways of controlling volatile organic compound (VOC) emissions at vegetable oil extraction plants. A cost-effectiveness analysis is included as an extension of the cost development.

4.1.2 Scope

Estimates of capital and annualized costs are presented for controlling VOC emissions from meal drying, meal cooling, meal product, and main vent sources in vegetable oil extraction plants. Since all plants are concerned with hexane losses and since the mode of process operation affects the cost effectiveness of the control options, two types of oil extraction plants are analyzed: well-operated plants and poorly operated plants. Cost analyses are performed for soybean plants and corn plants. The following control alternatives are analyzed for each type of plant:

1. Mineral oil scrubber (MOS) on the main vent associated with effective operation of the desolventizer toaster (DT).
2. MOS on the main vent and replacement of DT.
3. MOS on the main vent and carbon adsorbers for meal dryer and cooler emissions.

4. MOS on the main vent and incinerators for meal dryer and cooler emissions.

4.1.3 Use of Model Plants

The cost analysis is based solely on model sizes. Additional costs resulting from retrofitting the installation are considered, but no consideration has been given to detailed design characteristics of the model plants in terms of process equipment requirements, control system design, etc. It was necessary, however, to consider gas flow rates for model plants in order to size the VOC control systems.

It must be emphasized that model plants used in these analyses are ideal because they assume minimal space limitations for retrofitting the VOC control systems. The level of retrofit difficulty will alter the costs of control systems. Although control cost estimates based on model plants may differ from actual costs incurred, they are considered the best means of comparing relative costs and cost effectiveness of alternative control measures.

For purposes of estimating the cost effectiveness of various control options, the hexane recovery credit for a well-operated plant is based on the amount of hexane recovered over and above that recovered in a well-operated plant (i.e., one having a 90 percent efficient MOS and an effectively operated DT). The hexane recovery credit for the control options relative to a poorly operated plant is based on the amount of hexane recovered over and above that recovered in a poorly operated plant prior to upgrading.

4.1.4 Bases for Capital Cost Estimates

Capital costs represent the investment required for retrofitting a control system, including cost of equipment, material, labor for installation, and other associated costs. The capital cost estimates were developed by two different methods that include the same capital cost components such as equipment control and instrumentation, piping, ductwork, insulation, painting, etc. The methods of cost estimation were either to "build" an investment cost based upon the free on board (f.o.b.) equipment cost supplied by the manufacturer or to update investment costs that had been previously developed. The former method was employed to obtain the DT,[1] MOS,[2] and carbon adsorber[3,4,5] investment cost. The latter method was used to derive costs of afterburner systems with primary heat recovery.[6,7]

4.1.5 Bases for Annualized Costs

Annualized costs represent the cost of operating and maintaining the control system and of recovering the capital investment. Operating costs include costs of materials, utilities, and normal maintenance. The annualized costs also take into consideration the credit resulting from solvent recovery by emission control systems. All control equipment operating costs are estimated on an annual basis by the use of data from either the manufacturer or the literature. The unit costs and assumptions for the annualized costs are delineated in Table 4-1.

Table 4-1. COST FACTORS USED IN COMPUTING ANNUALIZED COSTS

I.	Annual operating time	6000 h for small and medium size plants 8000 h for large size plants
II.	Direct operating costs	
	1. Materials (as purchased)	
	- Carbon for adsorbers (5-yr life)[8]	$1.76/kg ($0.80/lb)[9]
	- Mineral oil for scrubbers (1-yr life)	$530 /$m^3$ ($2/gal)
	- Recovered hexane solvent	$0.19/kg ($0.085/lb)[10]
	2. Utilities	
	- Electricity	$0.0126/MJ ($0.0455/kWh)[11]
	- Steam [saturated, 100 kPa (15 psig)]	$0.01/kg ($3.30/1000 lb)
	- Natural gas	$0.07/$Nm^3$ ($2.01/1000 scf)[12]
	- Cooling water	$0.01/$m^3$ ($0.04/1000 gal)[13]
	3. Direct labor (0.5 man-hour/shift)	$10/man-hour[14]
	4. Maintenance charges	1% of capital investment[15]
III.	Annualized capital charges	
	1. Depreciation and interest	14.67% of capital cost
	2. Taxes and insurance	2% of capital cost
	3. Administrative overhead	2% of capital cost

The annualized cost analyses of model plants are provided as a means of comparing the relative costs of alternative control measures. The costs in actual practice may vary depending on factors such as material rates, utility costs, and total capital investment.

4.2 SOLVENT EMISSION CONTROL IN VEGETABLE OIL EXTRACTION PLANTS

4.2.1 Model Plant Parameters

Cost analyses are presented for three model sizes of vegetable oil extraction plants: small, medium, and large. These plants have a daily extractor feed cake processing capacity of 90, 640, and 1360 Mg (100, 700, and 1500 tons), respectively. Small and medium plants are assumed to operate 6000 h/yr, and large plants 8000 h/yr.

The exhaust volumes used for determining control costs of the main vent are 0.023, 0.041, and 0.087 m^3/s (48, 86, and 184 acfm) for plants having daily extractor feed cake processing capacities of 90, 640, and 1360 Mg (100, 700, and 1500 tons), respectively. Dryer and cooler exhausts are considered directly proportional to plant size for the model plant. Control costs of meal dryers are based on 0.115 m^3/s (244 acfm) per 90 Mg (100 tons) of daily extractor feed cake capacity, while control costs of meal coolers are based on 1.20 m^3/s (2550 acfm) per 90 Mg (100 tons) of daily extractor feed cake capacity. Exhaust temperature are estimated at 66°C (150°F) and 44°C (110°F) for the dryer and cooler, respectively.

The model plant cost analysis is performed for four control options discussed in Section 4.1.2. Hexane absorption by means of MOS units is

almost universally used in the industry to control emissions from the main vapor vent. These units, which handle relatively small gas flow rates, can achieve up to 98 percent removal of hexane from the stream when properly operated.

Effective operation of the DT or replacement with a more efficient DT decreases solvent emissions to the atmosphere because it decreases the solvent carryover to the meal dryer and cooler; hence, the DT can also be considered as an alternative for controlling solvent emissions from the meal dryer vent and cooler vent. For some plants though, process variables upstream may prevent a new DT from achieving full effectiveness. The operating and maintenance costs of DT's are considered part of processing cost and are not included in the costs of the control options.

Carbon-bed adsorbers may be applicable for removal and recovery of hexane in the exhaust streams from meal dryers and meal coolers. For both applications, however, removal of particulate matter is required prior to entry of the stream into the adsorber. The cost of a fabric filter is included in the adsorber system cost.

Afterburners with primary heat recovery can be employed for incinerating the solvent contents in the exhaust streams from meal dryers and coolers. Primary heat recovery is employed to reduce fuel requirements. Afterburners pose a fire risk because of high incinerating temperatures. Therefore, an isolated location is required for afterburners. Cost of an additional 30.5 m (100 ft) of ducting is included in the capital costs of model plants to allow for afterburner compliance with the National Fire Prevention Association requirement.[16]

4.2.2 Control Costs

Table 4-2 presents control costs of the four control options analyzed in this report. Costs are presented for three model sizes: small, medium, and large. The costs in Table 4-2 do not include the credit for recovered hexane. The capital costs of the afterburner include the cost of an additional 30.5 m (100 ft) of ducting. The capital cost of each option also includes the cost of monitoring equipment on the exhaust stacks. Three monitoring systems are assumed for each plant, one each for the main vent stack, dryer stack, and cooler stack.

4.3 COST EFFECTIVENESS

The emission control efficiencies and solvent emission reduction quantities are presented in Tables 4-3 through 4-6. These tables also indicate the solvent credit and cost effectiveness of each control option.

Cost-effectiveness curves are presented in Figures 4-1 through 4-4. For all the vegetable extraction plants analyzed in this report, control option No. 2 (MOS and replacement of DT) seems to be the most cost-effective option. This option also provides the maximum control efficiency among the options analyzed. The least cost-effective option is apparently an MOS coupled with an afterburner on the dryer and cooler. This is due to the high fuel requirements of the afterburner and also partly to the loss of hexane in this unit.

Table 4-2. COSTS OF SOLVENT CONTROL OPTIONS VEGETABLE OIL EXTRACTION PLANTS, $

Cost item, $	Control option											
	No. 1 MOS plus effective operation of DT			No. 2 MOS plus replacement of DT			No. 3 MOS plus carbon adsorbers for dryer and cooler			No. 4 MOS plus afterburners for dryer and cooler[a]		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
• Capital investment[b]												
Capital cost of control system	34,000	58,000	84,000	390,400	468,000	734,000	212,500	573,000	843,000	298,000	377,000	471,000
Capital cost of monitoring[c]	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Total capital investment	46,000	70,000	96,000	402,400	480,000	746,000	224,500	585,000	855,000	310,000	389,000	483,000
• Annual costs[d]												
Operation and maintenance cost	7,300	13,500	31,100	7,300	13,500	31,100	22,000	61,400	147,400	34,400	145,200	403,000
Capital charges, insurance, and overhead[e]	8,600	13,100	17,900	75,100	89,600	139,300	42,000	109,200	159,600	57,900	72,600	90,200
Total annualized cost	15,900	26,600	49,000	82,400	103,100	170,400	64,000	170,600	307,000	92,300	217,800	493,200

[a] Capital costs of afterburners include the cost of an additional 30.5 m (100 ft) of ducting.

[b] Capital cost is in November 1977 dollars.

[c] Monitoring system costs: $4000/stack, three stacks per plant.

[d] Does not include monitoring costs of approximately $2000 per year.

[e] 14.67% amortization, 2% insurance, and 2% administrative overhead.

Table 4-3. EMISSION REDUCTION AND COST EFFECTIVENESS DATA FOR CONTROL FACILITIES FOR A WELL-OPERATED SOYBEAN PLANT

Cost item	Control option											
	No. 1 MOS plus effective operation of DT			No. 2 MOS plus replacement of DT			No. 3 MOS plus carbon adsorbers for dryer and cooler			No. 4 MOS plus afterburners for dryer and cooler		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Solvent emissions controlled, kg/Mg of extraction feed cake processed	By definition these plants already incorporate control option no. 1			0.69	0.69	0.69	0.53	0.53	0.53	0.54	0.54	0.54
Solvent emission control efficiency, %				42	42	42	32	32	32	33	33	33
Solvent emission reduction, kg/yr				15,600	109,500	313,000	11,900	83,300	238,100	12,200	85,700	244,900
Annualized cost of control system, $				82,400	103,100	170,400	64,000	170,600	307,000	92,300	217,800	493,200
Annual credit for recovered hexane, $				2,900	20,500	58,700	2,200	15,600	44,600			
Net annualized cost (credit), $				79,500	82,600	111,700	61,800	155,000	262,400	92,300	217,800	493,200
Cost effectiveness (credit), $/kg of solvent controlled				5.10	0.75	0.36	5.29	1.86	1.10	7.57	2.54	2.01

Table 4-4. EMISSION REDUCTION AND COST EFFECTIVENESS DATA FOR CONTROL FACILITIES FOR A POORLY OPERATED SOYBEAN PLANT

Cost item	Control option											
	No. 1 MOS plus effective operation of DT			No. 2 MOS plus replacement of DT			No. 3 MOS plus carbon adsorbers for dryer and cooler			No. 4 MOS plus afterburners for dryer and cooler		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Solvent emissions controlled, kg/Mg of extractor feed cake processed	3.9	3.9	3.9	4.6	4.6	4.6	3.3	3.3	3.3	3.3	3.3	3.3
Solvent emission control efficiency, %	70	70	70	83	83	83	59	59	59	60	60	60
Solvent emissions controlled, kg/yr	88,500	619,200	1,769,000	104,100	728,700	2,082,000	74,000	518,300	1,481,000	76,000	529,500	1,512,700
Annualized cost of control system, $	15,900	26,600	49,000	82,400	103,100	170,400	64,000	170,600	307,000	92,300	217,800	493,200
Annual credit for recovered hexane, $	7,206	50,600	144,500	19,500	136,600	390,200	13,900	97,100	277,300	7,200	50,600	144,500
Net annualized cost (credit), $	8,700	(24,000)	(95,500)	62,900	(33,500)	(219,800)	50,100	73,500	29,700	85,100	167,200	348,700
Cost effectiveness (credit), $/kg of solvent controlled	0.10	(0.04)	(0.05)	0.60	(0.05)	(0.11)	0.68	0.14	0.02	1.12	0.32	0.23

Table 4-5. EMISSION REDUCTION AND COST EFFECTIVENESS DATA FOR CONTROL FACILITIES FOR A WELL-OPERATED CORN PLANT

Cost item	Control option											
	No. 1 MOS plus effective operation of DT			No. 2 MOS plus replacement of DT			No. 3 MOS plus carbon adsorbers for dryer and cooler			No. 4 MOS plus afterburners for dryer and cooler		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Solvent emissions controlled, kg/Mg of extractor feed coke processed	By definition these plants already incorporate control option no. 1			0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3
Solvent emission control efficiency, %				34	34	34	26	26	26	27	27	27
Solvent emissions controlled, kg/yr				9,300	65,100	186,000	7,000	49,200	140,600	7,300	51,000	145,800
Annualized cost of control system, $				82,400	103,100	170,400	64,000	170,600	307,000	92,300	217,800	493,200
Annual credit for recovered hexane, $				1,700	12,200	34,900	1,300	9,200	26,400			
Net annualized cost (credit), $				80,700	90,900	135,500	62,700	161,400	280,600	92,300	217,800	493,200
Cost effectiveness (credit), $/kg of solvent controlled				8.68	1.40	0.73	8.96	3.28	2.00	12.64	4.27	3.38

Table 4-6. EMISSION REDUCTION AND COST EFFECTIVENESS DATA FOR CONTROL FACILITIES FOR A POORLY OPERATED CORN PLANT

Cost item	Control option											
	No. 1 MOS plus effective operation of DT			No. 2 MOS plus replacement of DT			No. 3 MOS plus carbon adsorbers for dryer and cooler			No. 4 MOS plus afterburners for dryer and cooler		
	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large	Small	Medium	Large
Solvent emissions controlled, kg/Mg of extractor feed cake processed	3.0	3.0	3.0	3.4	3.4	3.4	2.6	2.6	2.6	2.7	2.7	2.7
Solvent emission control efficiency, %	71	71	71	81	81	81	63	63	63	63	63	63
Solvent emissions controlled, kg/yr	68,000	476,300	1,360,800	77,300	541,400	1,546,800	59,500	416,700	1,190,700	60,400	429,100	1,208,800
Annualized cost of control system, $	15,900	26,600	49,000	82,400	103,100	170,400	64,000	170,600	307,000	92,300	217,800	493,200
Annual credit for recovered hexane, $	7,200	50,600	144,500	14,500	101,400	289,900	11,200	78,100	223,100	7,200	50,600	144,500
Net annualized cost (credit), $	8,700	(24,000)	(95,500)	67,900	1,700	(119,500)	52,800	92,500	83,900	85,100	167,200	348,700
Cost effectiveness (credit), $/kg of solvent controlled	0.13	(0.05)	(0.07)	0.88	0.00	(0.08)	0.89	0.22	0.07	1.41	0.39	0.29

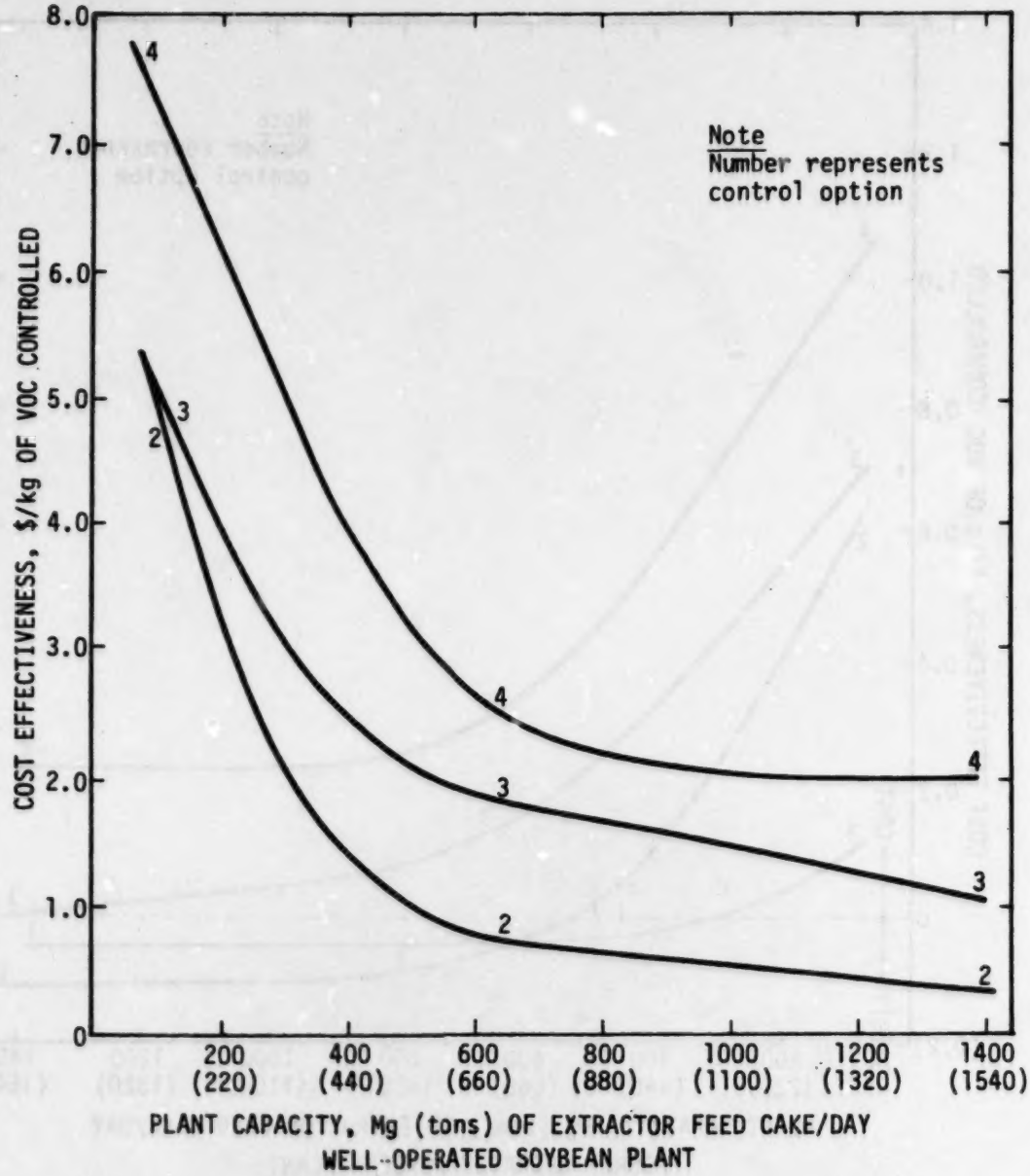

Figure 4-1 Cost-effectiveness curves for a well-operated soybean plant

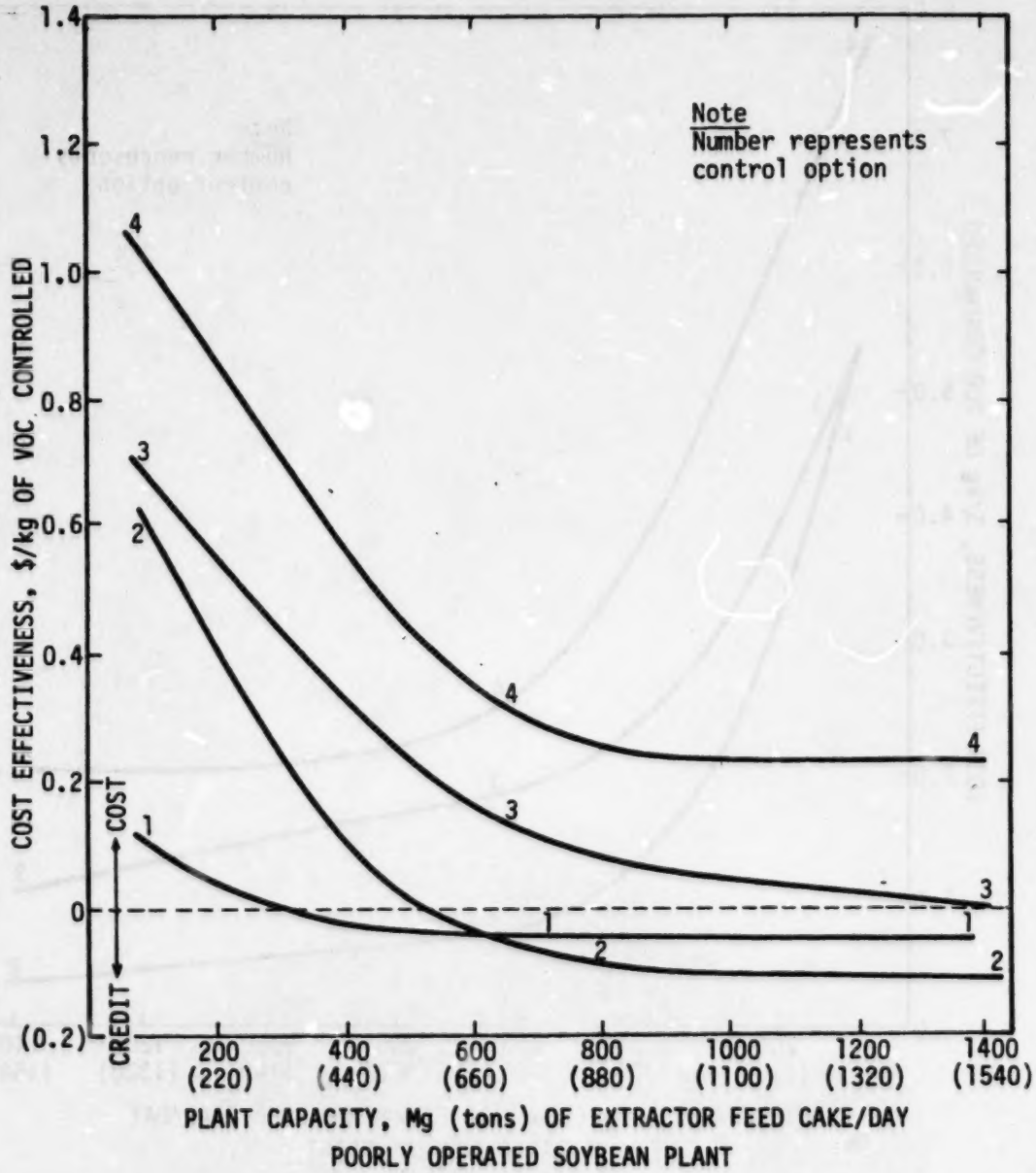

Figure 4-2. Cost-effectiveness curves for a poorly operated soybean plant

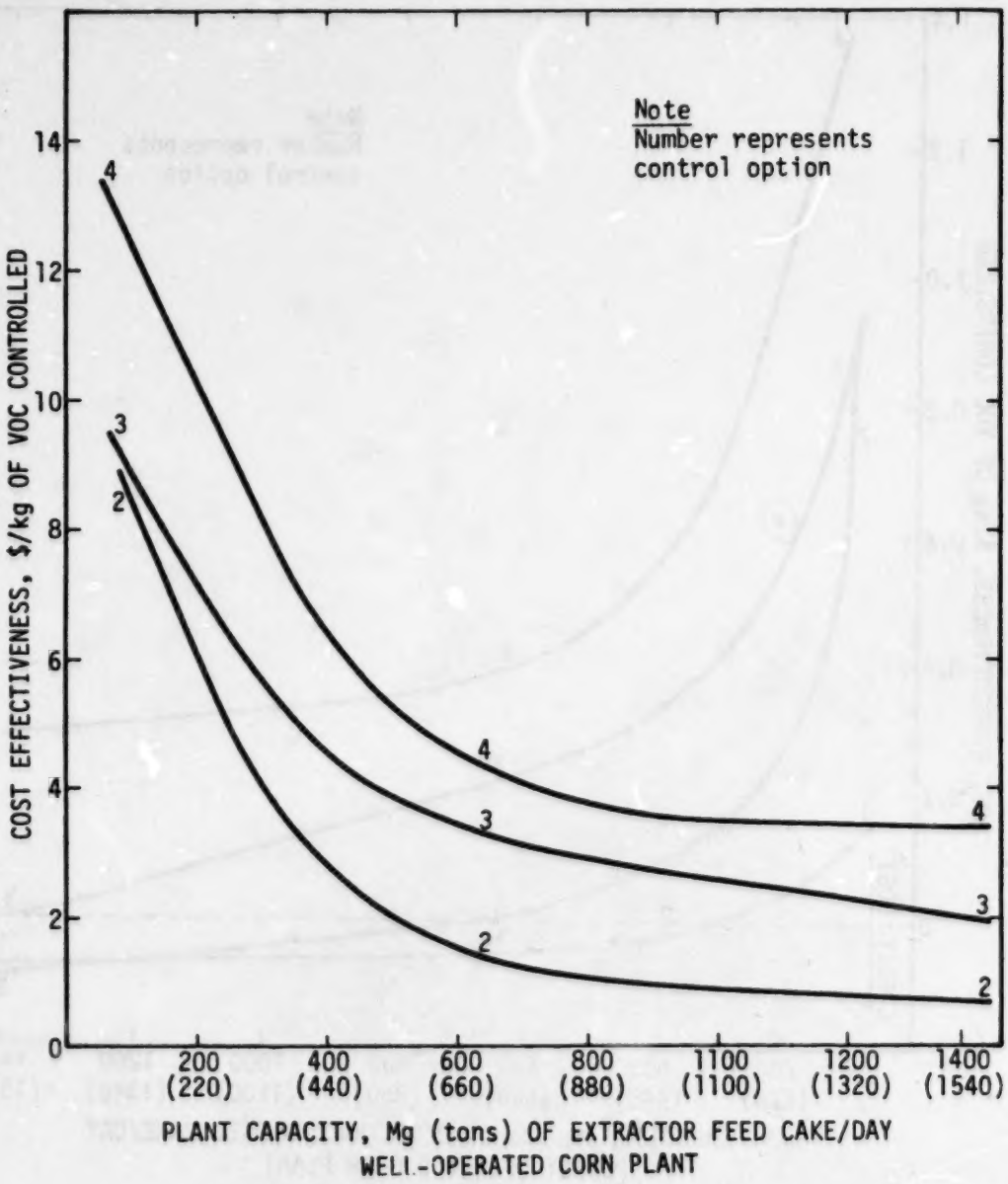

Figure 4-3. Cost-effectiveness curves for a well-operated corn plant

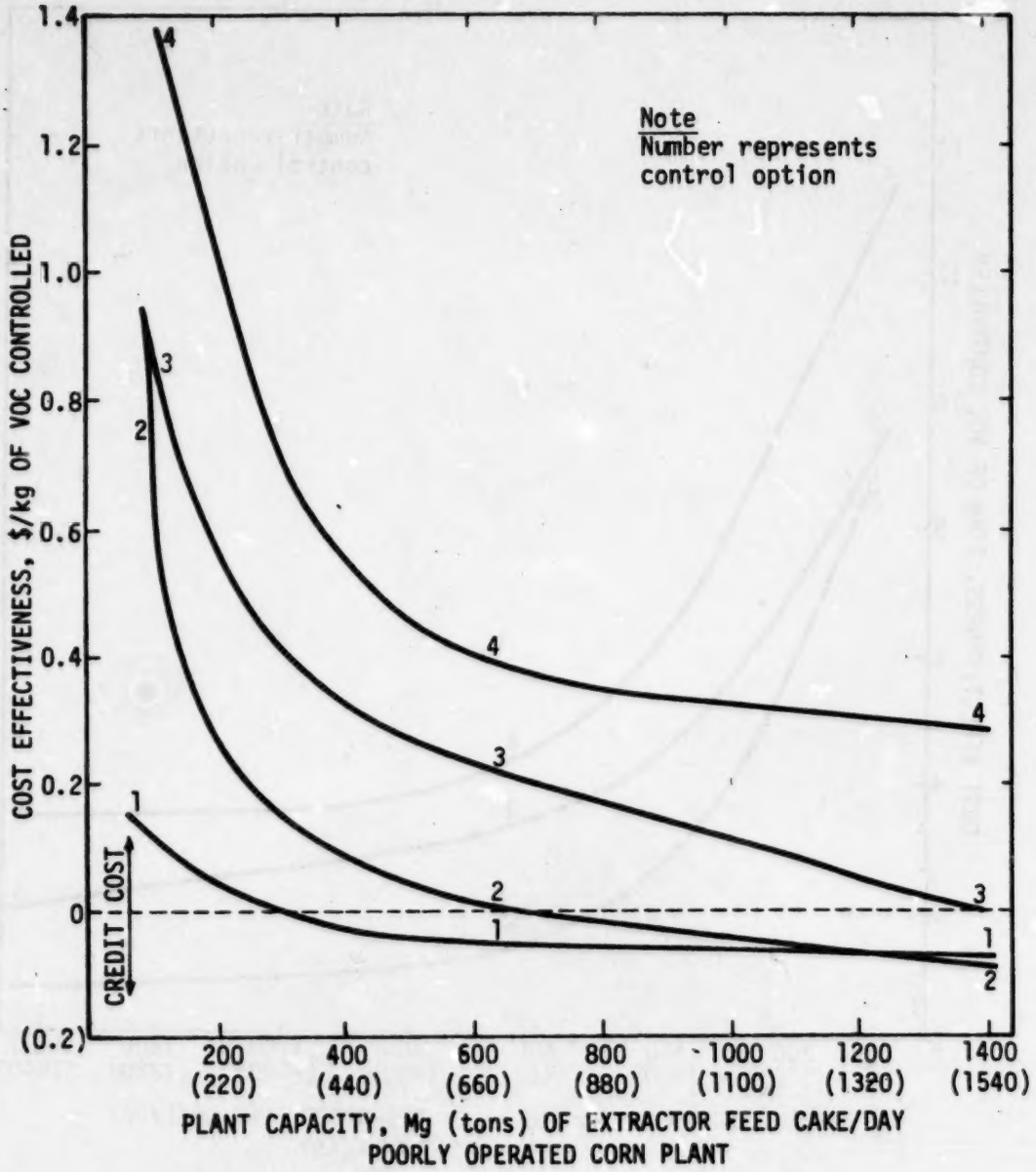

Figure 4-4 Cost-effectiveness curves for a poorly operated corn plant

4.4 SUMMARY

Cost analyses of model plants indicate that the cost of emission control in the vegetable oil industry is sensitive to the amount of solvent recovered. The increasing value of hexane used in oil extraction plants causes emission control with more effective hexane recovery to be increasingly attractive economically as well as necessary for compliance with emission standards.

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5.0 ADVERSE EFFECTS OF APPLYING THE TECHNOLOGY

This chapter addresses the fuel/energy requirements for applying the control technology discussed in Chapter 3.0. Also discussed is the impact of these energy expenditures with regard to air, water, and solid waste pollution.

5.1 MINERAL OIL SCRUBBER

The mineral oil scrubber (MOS) requires steam for heating and stripping the mineral oil and electrical energy to pump the oil. Efficient operation of an MOS depends on the amount of air introduced into the system. For purposes of assessing the energy impacts, it is assumed that the plant is fairly well-operated and the main vent exhaust volume is 3 Nm^3 (100 scf) per 0.91 MFC*(1 TFC).[1] Daily energy requirements are generally proportioned to plant size, although smaller plants have slightly higher air requirements due to the introduction of air into the system from miscellaneous leaks. This infiltration rate does not decrease in proportion to plant size. Annual energy requirements for MOS operation, by plant size, are shown in Figure 5-1. Secondary pollutants based on the following emission factors are shown in Table 5-1:

Pollutant	Allowable Emissions Mg/KJ ($lb/10^6$Btu)	Kg/Mg (lb/ton) coal
Particulate Matter	0.04 (0.1)	1.2 (2.4)
Sulfur Dioxide	0.86 (2)	24 (48)
Hydrocarbon	0.02 (0.04)	0.5 (1)
Nitrogen Oxide	0.26 (0.6)	7.5 (15)
Carbon Monoxide	0.03 (0.08)	1 (2)

* MFC megagrams of extractor feed cake
TFC tons of extractor feed cake

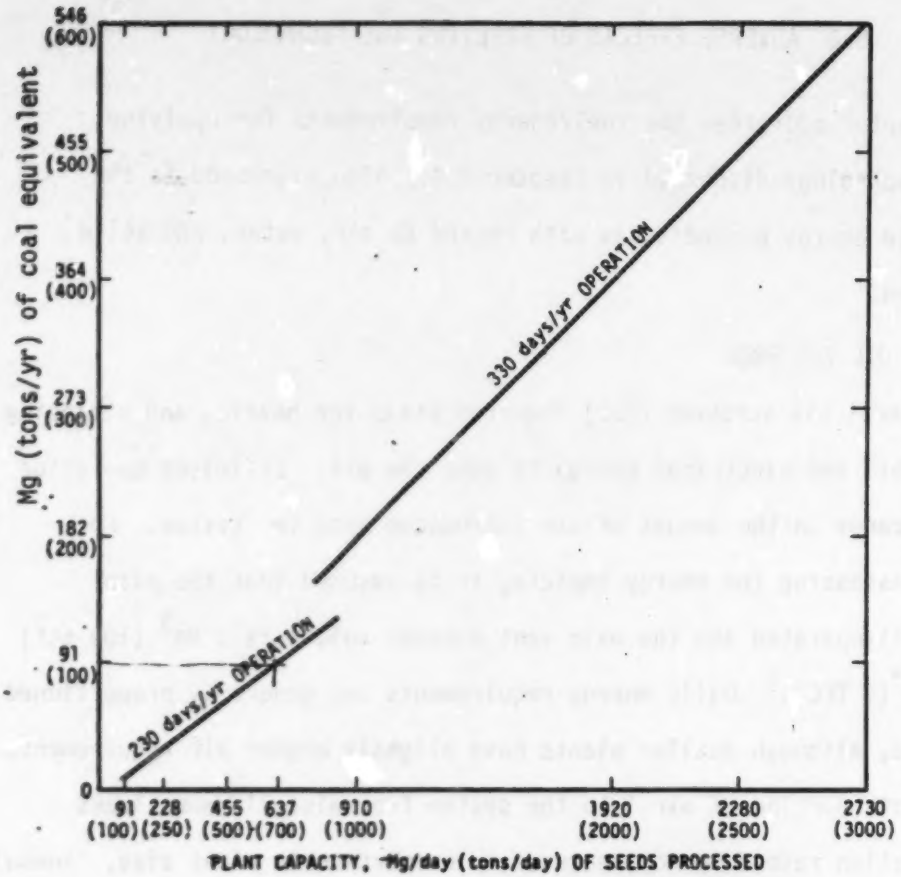

Figure 5-1. Annual fuel requirements for a mineral oil scrubber on the main vent of a soybean plant.

Table 5-1. SECONDARY POLLUTANTS RESULTING FROM USE OF MINERAL OIL SCRUBBER ON MAIN VENT

Plant size, Mg/day (tons/day) seeds processed	Emissions, Mg/yr (tons/yr)				
	Part	SO_2	HC	NO_2	CO
90 (100)	0.009 (0.01)	0.182 (0.2)	0.004 (0.005)	0.073 (0.08)	0.009 (0.01)
230 (250)	0.036 (0.04)	0.636 (0.7)	0.018 (0.02)	0.182 (0.2)	0.027 (0.03)
450 (500)	0.073 (0.08)	1.545 (1.7)	0.036 (0.04)	0.454 (0.5)	0.636 (0.7)
910 (1000)	0.182 (0.2)	4.364 (4.8)	0.091 (0.1)	1.364 (1.5)	0.182 (0.2)
1820 (2000)	0.454 (0.5)	8.727 (9.6)	0.182 (0.2)	2.727 (3.0)	0.364 (0.4)
2730 (3000)	0.636 (0.7)	13.091 (14.4)	0.273 (0.3)	4.091 (4.5)	0.545 (0.6)

Very little water or solid waste pollution results from the use of an MOS. The collected solvent is recycled and the mineral oil itself theoretically lasts indefinitely as long as the system is properly operated. (In actual practice the mineral oil is replaced once or twice a year.) If the mineral oil heater fails, however, the oil will mix with condensate from the condensing stream to form an emulsion. This emulsion must be replaced. When the oil must be replaced, it is put into drums and hauled away by a waste oil dealer and normally sold to asphalt plants for use as fuel.

5.2 INSTALLATION OF A NEW DESOLVENTIZER-TOASTER

The purpose of a desolventizer-toaster is to recover hexane from the flakes and to produce a marketable meal product. New desolventizer-toasters are generally more than twice as efficient for solvent removal than older, reasonably well-operated ones. Incorporation of this equipment has no adverse environmental impacts.

5.3 CARBON BED ADSORBER

Carbon bed adsorbers require stripping steam and electrical energy to drive the gases through the carbon bed. When used to control dryer and cooler vent emissions, typical energy requirements for a 910 Mg/day (1000 ton/day) plant are as follows:

	Steam Kg/s (lb/hr)	Electrical[4] Power, kW
Dryer[2]	0.05 (400)	25
Cooler[3]	0.08 (600)	75

Annual energy requirements are shown in Figure 5-2. Secondary emissions are estimated using the same emission factors as the MOS as shown in Table 5-2. The activated carbon used in the adsorbers has a life of approximately 5 years.[5] At the end of its useful life, the carbon is replaced with a new charge. The spent carbon is reactivated for use elsewhere. It does not enter the solid waste stream.

5.4 INCINERATION

Exhausts from the dryer vent and cooler vent may be introduced to an afterburner, where the hexane vapors are incinerated. This control method requires no waste disposal or recycling of adsorbent agent. It has its drawbacks, however, in that it destroys the hexane and requires a large quantity of fuel even with heat recovery. Pollutants in the products of combustions would be emitted as shown in Table 5-3. Annual gas consumption is shown in Figure 5-3.

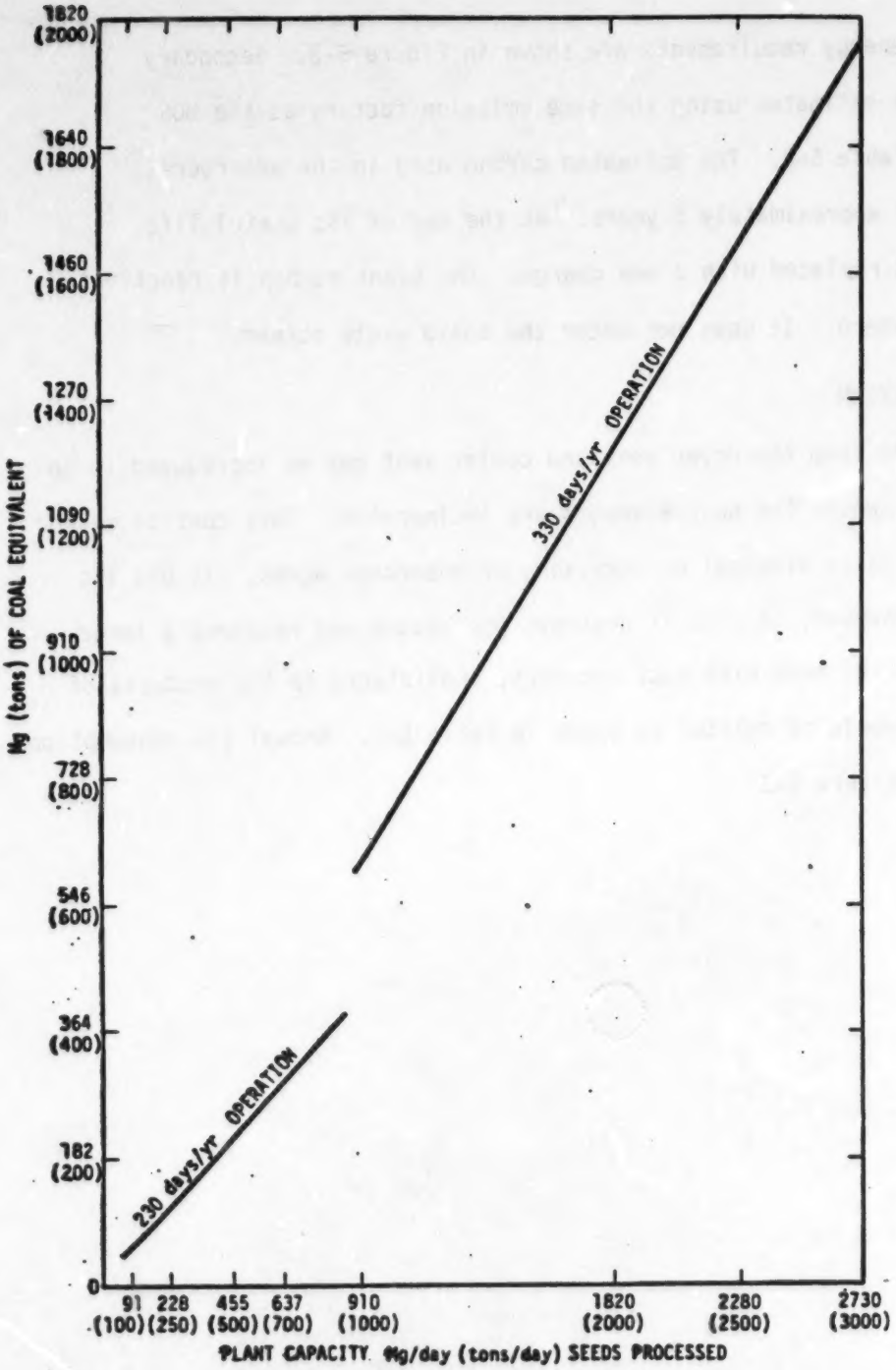

Figure 5-2. Annual fuel requirements for carbon-bed adsorbers controlling both the dryer vent and cooler vent.

Table 5-2. SECONDARY POLLUTANTS RESULTING FROM USE OF ADSORBER ON DRYER AND COOLER VENTS

Plant size, Mg/day (tons/day) seeds processed	Emissions, Mg/yr (tons/yr)				
	Part	SO_2	HC	NO_2	CO
90 (100)	0.05 (0.055)	1.0 (1.1)	0.021 (0.023)	0.032 (0.035)	0.042 (0.046)
230 (250)	0.13 (0.14)	2.54 (2.8)	0.054 (0.06)	0.082 (0.09)	0.109 (0.12)
450 (500)	0.25 (0.28)	5.0 (5.5)	0.100 (0.11)	0.164 (0.18)	0.209 (0.23)
910 (1000)	0.72 (0.79)	14.36 (15.8)	0.300 (0.33)	0.454 (0.50)	0.600 (0.66)
1820 (2000)	1.45 (1.6)	28.73 (31.6)	0.600 (0.66)	0.909 (1.0)	1.182 (1.3)
2730 (3000)	2.18 (2.4)	43.18 (47.5)	0.909 (1.0)	1.364 (1.5)	1.818 (2.0)

Table 5-3. SECONDARY POLLUTANTS RESULTING FROM USE OF A PRIMARY RECOVERY TYPE AFTERBURNER ON DRYER AND COOLER VENTS.

Plant size, Mg/day (tons/day) seeds processed	Emissions, Mg/yr (tons/yr)				
	Part	SO_2	HC	NO_2	CO
90 (100)	0.028 (0.031)	0.0017 (0.0019)	0.023 (0.025)	0.28 (0.31)	0.056 (0.062)
230 (250)	0.071 (0.078)	0.0043 (0.0047)	0.056 (0.062)	0.71 (0.78)	0.142 (0.156)
450 (500)	0.141 (0.155)	0.0845 (0.093)	0.113 (0.124)	1.41 (1.55)	0.282 (0.310)
910 (1000)	0.409 (0.450)	0.0245 (0.027)	0.327 (0.360)	4.09 (4.50)	0.818 (0.90)
1820 (2000)	0.818 (0.900)	0.0491 (0.054)	0.654 (0.720)	8.18 (9.0)	1.636 (1.80)
2730 (3000)	1.227 (1.35)	0.0736 (0.081)	0.982 (1.08)	12.27 (13.5)	2.454 (2.70)

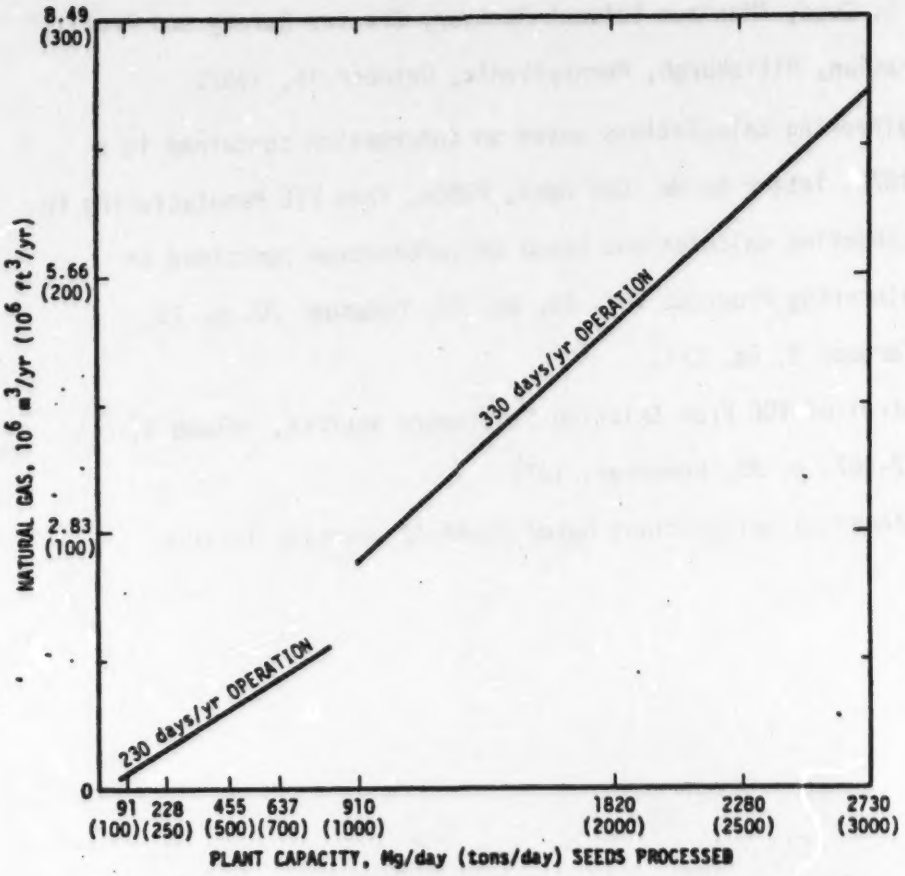

Figure 5-3. Annual natural gas requirements for a direct-fired afterburner (with primary recovery) controlling both the dryer vent and cooler vent.

5.5 REFERENCES

1. R. D. Good, "Maximum Solvent Recovery Creates Safety and Profit," Dravo Corporation, Pittsburgh, Pennsylvania, October 16, 1967.

2. Engineering calculations based on information contained in a January 6, 1978, letter to Mr. Don Henz, PEDCo, from VIC Manufacturing Co.

3. Engineering calculations based on information contained in Chemical Engineering Progress Vol. 65, No. 12, December 70, p. 75.

4. Reference 2, Op. Cit.

5. Control of VOC From Existing Stationary Sources, Volume 1, OAQPS No. 1.2-067, p. 35, November, 1976.

6. Engineering calculations based on AP-42 emission factors.

6.0 ENFORCEMENT ASPECTS

The purpose of this chapter is to define facilities to which regulations will apply, select appropriate regulatory format, and to recommend emission limits which represent RACT. Compliance and monitoring techniques are also recommended in this chapter.

6.1 AFFECTED FACILITY

In formulating regulations, it is recommended that the affected facility be defined as the extraction system, from the extractor to the cooler (or pneumatic flake conveyor). As discussed in Chapter 2, the principal emission points include but are not limited to:

1. Extractor
2. Desolventizer or desolventizer-toaster
3. Dryer
4. Cooler
5. Pneumatic flake conveyor

RACT for the major sources is defined as follows:

A. Extractor

Major extractor losses are through the main vent. Solvent emissions from the main vent are effectively controlled with a mineral oil scrubber (MOS). This device can reduce main vent emissions by 90 to 95 percent. Carbon-bed adsorbers are also effective on this vent, but have found very limited use.

Limitation of this vent stream to a concentration of 9000 ppm is currently achievable with a mineral oil scrubber. This will reduce hexane emissions from a 910 Mg/day (1000 ton/day) plant from 5400 kg/day to 500 kg/day (11,900 to 1,100 lb/day). Emissions of VOC will be reduced by 5.4 kg/MFC (10.7 lb/TFC) or more by application of a mineral oil scrubber on the main vent.

B. Desolventizer, Dryer, Cooler, Pneumatic Conveyor

These sources each discharge to the atmosphere through separate vents. No attempt is currently made to capture the hexane in these gas streams. These losses, however, are a function of the efficiency of the desolventizing equipment. Thus VOC discharges from these vents may be limited by means of vent control or process control. New desolventizer-toasters (DT) desolventize flakes to the 500 ppm level. Reasonably well-operated plants desolventize to a level of about 1350 ppm hexane. This is approximately 1.35 kg/Mg (2.7 lb/ton) of desolventized flakes. Smaller plants without dryers and coolers pneumatically convey the desolventized flakes to the meal conditioning area. Approximately half of the entrained solvent (about 0.7 kg/Mg desolventized meal) is lost in the dryer-cooler arrangement or, in smaller plants, along the pneumatic conveyor.

Properly operated and maintained desolventizing equipment is capable of reducing the level of hexane in desolventized meal well below 1350 ppm. Plants not able to achieve this concentration can control their emissions with carbon-bed adsorbers or incinerators installed on the dryer and cooler vents. Carbon-bed adsorbers and incinerators reduce emissions by 90 to 99 percent.

6.2 MONITORING AND COMPLIANCE

The main vent stack and the meal leaving the desolventizer-toaster should be monitored by operating personnel weekly during the first year. After the first year, the data should be reviewed so that monitoring and reporting requirements can be adjusted as necessary.

Analytical methods for determining the hexane concentration of meal from the desolventizer are being investigated. Pending completion of the evaluation, no test method is recommended at present.

APPENDIX A

Table A-1 ESTIMATED AVERAGE SOLVENT LOSSES FROM REASONABLY WELL-OPERATED COTTONSEED AND SOYBEAN PLANTS BASED ON CLEAN, RAW SEED INPUT (Metric Units)

Point of solvent loss	Solvent loss, kg/Mg raw seed		
	Cottonseed		
	Prepress plant	Full solvent plant	Soybeans
A. Operational losses			
Meal drying[a,b]	0.18	0.18	0.32
Meal cooling[a,b]	0.12	0.12	0.22
Meal product[a,b]	0.30	0.30	0.55
Oil[c,d]	0.08	0.16	0.18
Waste water[e]	0.02	0.05	0.05
Main vent (uncontrolled)[f]	3.13	3.55	5.90
Solvent storage[g]	0.04	0.09	0.10
Fugitive (leaks)[h]	0.30	0.59	0.33
Total operational losses	4.17	5.04	7.65
B. Non-operational losses			
Start-up & shutdown[i]	0.18	0.20	0.16
Downtime[i]	0.18	0.20	0.16
Total uncontrolled losses (rounded)	4.5	5.4	8.0
Less solvent collected in absorber (average)[j]	2.7	3.2	5.4
Total controlled losses	1.8	2.2	2.6

FOOTNOTES TO TABLE A-1

a) Based on 1 kg (2.2 lb) total loss in meal.[1] This is the amount of solvent in the soybean meal as it exits the desolventizer-toaster (DT). It represents a solvent content of approximately 1300 ppm. Approximately 30 percent of this is lost in the dryer and approximately 30 percent of the remainder is lost in the cooler.

b) Based on a meal content of 450 kg/Mg (900 lb/ton) of clean raw cottonseed. Meal exiting the DT has same solvent concentrations as soybean meal. See Footnote (a).

c) Based on 0.1 solvent content and 163 kg(360 lb) soybean oil per 0.91 Mg (1 ton) of clean, raw seed and 145 kg (320 lb) cottonseed oil per 0.91 Mg (1 ton) of clean, raw seed.

d) See Footnote (c). Oil from a prepress plant contains an average of only 0.05 percent solvent since only half the oil is extracted using solvent.

e) This assumes a direct function of solvent input to extractor. Approximately 2.7 kg (6 lb) solvent is required per kg (lb) of oil in the extractor feed cake. Thus, soybean plants and full solvent cottonseed plants require approximately 910 kg (200 lb) solvent per 0.91 Mg (1 ton) of clean, raw seed, and a prepress plant requires about half that amount.

f) This is directly proportional to the volume of air introduced into the system which, in turn, is approximately proportional to the weight of the feed to the extractor. It is estimated that 1.8 Nm^3 (65 scf) is introduced per 0.91 Mg (1 ton) of soybean flakes and another 1 Nm^3 (35 scf) is introduced as a result of equipment leaks. Using this same ratio, approximately 1.7 Nm^3 (60 scf) air per 0.91 Mg (1 ton) of white seed is introduced into a cottonseed full-solvent air extraction process. The gases leaving the main vent condenser are approximately 38°C (100°F) and saturated with hexane. Thus the stream is approximately 35 percent (volume) hexane. This is approximately 1.5 m^3 (55 ft^3). In summary, solvent loss is assumed to be directly proportional to the weight of the extractor feed cake.

g) Proportional to solvent usage. Estimated loss for soybean oil plants is 0.1 kg/Mg (0.2 lb/ton) of beans processed.[2] Solvent usage is approximately 3 kg/Mg (6 lb/lb) of oil in the extractor feed cake.

h) Generally not proportional to plant size. It is dependent on leaks from valve packings, pump seals, gaskets and the like. Estimated fugitive losses from 910 Mg/day (1000 tons/day) of soybean plants are 0.33 kg/MFC (0.66 lb/TFC), and smaller plants have a higher loss rate.[3] Cottonseed, corn, and peanut plants are smaller than soybean plants, and fugitive losses are estimated at 100 percent higher per kg (lb) of oil which is solvent extracted.

i) Estimated at 0.16 kg/MFC (0.33 lb/TFC) for 910 Mg/day (1000 tons/day) of soybean plants.[4] Smaller plants such as cottonseed oil mills assumed to have a loss double that rate.

j) Based on information given in published papers [5,6], the average efficiency of mineral oil adsorbers on the main vent is approximately 90 percent.

REFERENCES

1. George Anderson. 5 Point Process Efficiency. Crown Iron Works Company, Minneapolis, Minnesota, 1976.

2. Ibid.

3. Ibid.

4. Ibid.

5. Ibid.

6. Robert D. Good, Dravo Corporation. Maximum Solvent Recovery Creates Safety and Profit. Presented to the American Oil Chemists Society, Chicago, Illinois, 1967. pp. 1-17.